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Status and Pedogenetic Distribution of Selected Extractable Micronutrients in Mambilla Plateau-Montane Soils of Nigeria

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Abstract

Mambilla Plateau is widely utilized for agricultural production, not much is known about the pedogenic concentration of the soil micronutrients there. The purpose of this study was to assess the pedogenic concentration and current state of a few selectable micronutrients in a few soil samples from the Mambilla Plateau in Taraba State, Northeastern Nigeria. Twelve profile pits in all were excavated to serve as sampling units. The profile pits' pedogenetic strata provided samples of soil, which were then gathered, processed, and examined. The profile pits' sand content ranged from 28.24 to 86.88 %. Total exchangeable bases ranged from low to medium (4.58 to 9.17 cmol kg^{-1}), organic carbon (OC) varied from low to high (2.40 to 36.00 g/kg), and soil pH varied from slightly acidic to highly acidic (5.15 to 6.32). Cu(2.8–5.3 mg kg^{-1}) was over the critical limit, but available Zn(0.010–0.022 mg kg^{-1}), Cu(0.020–0.034 mg kg^{-1}), and Fe(0.21–0.45 mg kg^{-1}) were below it. Sand and OC showed a significantly substantial positive association with available Zn, Cu, and Fe. There would be a need to apply soil amendments to supplement the soil with micronutrients for successful and profitable crop production.

Keywords: Mambilla Plateau; micronutrients; soil properties; soil relationships

Introduction

Mambilla Plateau is an area where most of her populace are basically agrarians. Because of this, there has been constant, intense farming, which lowers soil micronutrient levels. According to Yusufu and Abenu (2019), a reduction in soil micronutrients impedes plant growth at its best and agricultural sustainability. According to Kingsley et al. (2019), micronutrients are metallic chemical elements that plants need in small amounts. They are also crucial as macronutrients in terms of agronomy. These elements, which include copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), among others, are essential for the biosynthesis of protein, the production of vitamin A in plants, growth factors, the metabolism of carbohydrates and fats through their participation in various plant enzymatic systems, the regulation of respiration and photosynthesis, the enhancement of plant tissues' ability to hold water(Mulima et al., 2015; FAO, 2011). According to the evaluations of soil micronutrients, there is relatively little difference in the limits for sufficient, deficient, and harmful amounts. Studies by Domchang et al. (2014) and Oluwadare et al. (2013) indicated that micronutrient deficiencies have been identified more often in the past few years. The erroneous and inappropriate application of fertilizers may be the cause of these deficits. According to Hassan and Ogbonnaya (2016), one of the key factors that caused agrarians to recognize the importance of balanced fertilization in crop productivity was their realization of micronutrient deficiencies in the soil.

The distribution of soil micronutrients might differ among profiles created using various parent materials and landforms (Verma et al., 2005). Micronutrient removal from the soil has increased dramatically since high-yielding enhanced cultivars were introduced. The earth minerals found in the pedosphere are what replenish micronutrients in soils. Micronutrients in soil vary geographically as a result of pedospheric differences brought about by parent material, terrain, climate, etc. (Katyal and Sharma, 1991). In order to address the issues related to soil micronutrient deficiencies, it is now crucial to evaluate the micronutrient status of soils and make the necessary corrections. According to Bichi and Ibrahim (2018), agricultural output is controlled by the most limiting factor, hence efforts to increase crop productivity through watering, fertilizing, and other means may be ineffective even if a single micronutrient turns out to be a limiting factor. In the majority of Nigeria's soils, the reduction in soil fertility brought on by micronutrient deficiencies is turning into a serious problem. As a result, sufficient information regarding the soil's innate ability to give nutrients from lower soil layers must be gathered in order to adjust nutrients in the field effectively (Setia and Sharma, 2004). The distribution of nutrients in soils is closely related to pedogenic development.

Few or no studies have looked at how soil micronutrient concentration relates to profile depth in the Mambilla Plateau to promote agricultural production and ecosystem balance. The information provided by this study is necessary to comprehend the condition and variability of micronutrients in the different soil types found in the Mambilla Plateau. Planning soil management treatments to maintain micronutrient levels at adequate levels and address deficiencies in the study site will benefit from the data collected.

Materials and Methods

The Mambilla Plateau (Fig. 1), whose total land area is 3,765.2 km^2, is situated between latitudes 6^{o} 30′ 24″ to 7^{o} 19′ 48′¸ N and longitudes 11^{o} 02′ 42″to 11^{o} 37′ 12″ E. It forms the southernmost tip of Nigeria's northeast region. The Sardauna Local Government Area in Taraba State Northeast, Nigeria, encompasses the entire plateau. With peaks in June/July and September, the average yearly rainfall ranges from 1780 mm to 2200 mm (Chapman and Chapman, 2000). Between 25 and 35 degrees Celsius is the average yearly temperature (Bami, 2013). The Nigerian Montane Guinea Savanna zone includes the Mambilla Plateau. The plateau's vegetation consists mostly of short grasses, with very few trees—aside from artificial forests—growing on it. The geology of the Mambilla Plateau is developed on Basement Complex rocks. Using a flexible grid sample technique, a total of 12 profile pits measuring 2 m × 1.8 m × 2 m were dug, one on each grid. Soil Survey Staff (2017) provided instructions for the description and sampling of the profile pits. For standard laboratory analysis, the samples were air-dried, crushed, and put through a 2.0 mm and 0.5 mm mesh sieve. The following characteristics of the soil were found. The Bouyoucos hydrometer method was used to determine the particle size distribution (Gee and Or, 2002). Using a glass electrode pH meter with a solid-liquid (water) ratio of 1:2.5, the pH of the soil was measured electrometrically (Thomas, 1996). According to Thomas's (1982) instructions, exchangeable bases were identified using the neutral ammonium acetate method buffered at pH 7.0. The wet digestion procedure as outlined by Nelson and Sommers (1982) was used to measure total carbon. According to Sahlemedhin and Taye (2000), the available micronutrients (iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn)) were extracted using DTPA, and an atomic absorption spectrophotometer was used to test each micronutrient.

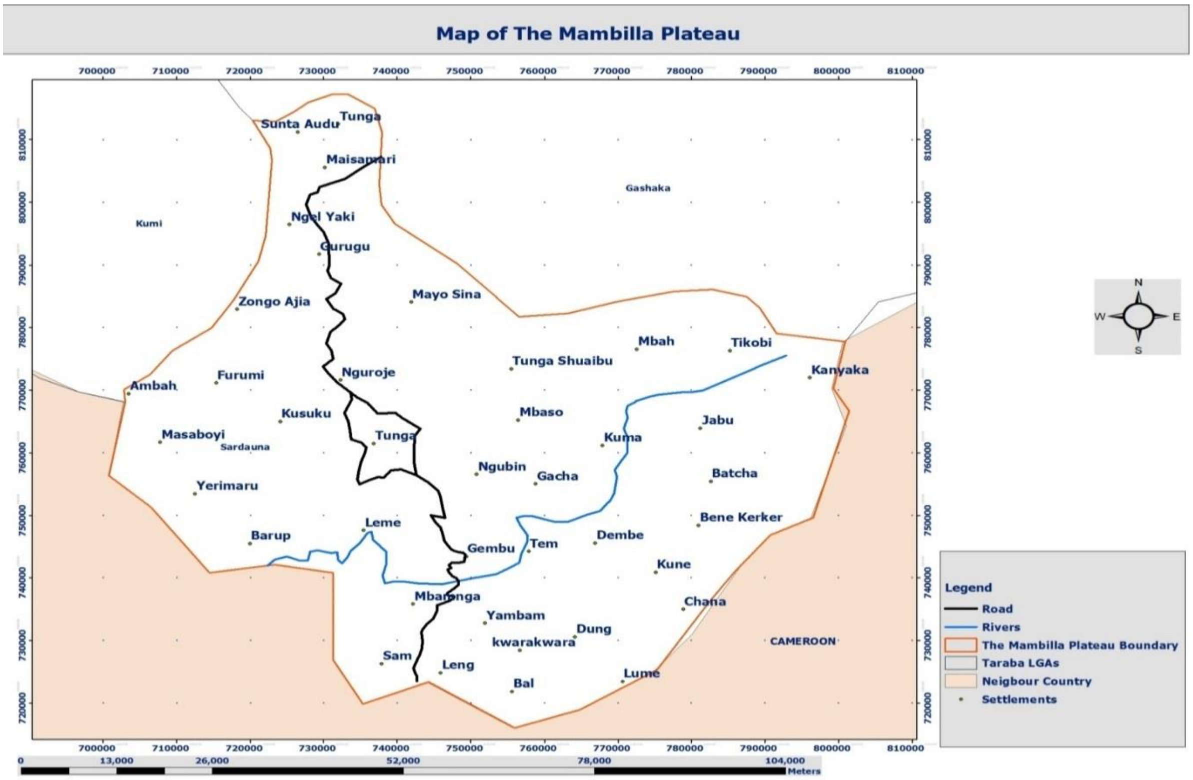

Fig. 1. *Map of the Mambilla Plateau*

Results and Discussion

According to the results (Table 1), the horizons' sand content ranged from 28.24 to 86.88 % throughout the profiles. In every soil horizon of the profiles that were examined, sand content predominated the mineral fraction. This may be partially explained by parent material that was high in quartz mineral, which is a necessary ingredient in granite Wilson (2010). Sand often makes up the majority of the soil's particle size fraction, followed by clay and then silt. Osujieke *et al.* (2018; 2020) and Lawal *et al.* (2013) have revealed comparable outcomes in their studies conducted within the Guinea savannah region of Nigeria.

With the exception of profiles 6 and 8, whose sand content declined with profile depth in a regular pattern, the distribution of sand content in the profiles showed an erratic pattern as it decreased. The silt fraction varied between the profiles, ranging from 3.28 to 37.20 %. There is no clear pattern in the silt content distribution pattern with respect to profile depth. The profiles' horizons showed a range of 7.28 to 62.48 % of clay concentration. With the exception of profiles 6 and 8, which exhibited a consistent pattern of decline with profile depth, the clay content values in the majority of profiles lacked a clear pattern of distribution. Variations in the weathering of parent material may be linked to the irregular pattern in clay distribution with profile depth (Sekhar et al., 2014).

Table 1. *Physico-chemical properties of the soils of Mambilla Plateau*

Horizon	Depth	Sand	Silt	Clay	pH	OC	TEB	ECEC
	(cm)	→	% ←		(H_2O)	(g/kg)	→	cmol/kg ←
Profile 1(Jabu) (N06°53′52.8″ E011°24′13.9″ and elevation= 1567 m)								
Ap	0 – 29	74.80	11.00	14.20	5.70	34.90	7.06	8.14
Bt1	29 – 48	62.80	11.00	26.20	5.78	15.60	5.94	6.94
Bt2	48 – 71	67.80	12.00	20.20	5.83	14.40	6.22	7.31
Bt3	71 – 86	65.80	11.00	23.20	5.81	15.20	6.23	7.30
Bt4	86 – 120	64.80	12.00	23.20	5.81	16.60	6.00	7.06
Bt5	120 – 180	58.80	17.00	24.20	5.78	25.10	7.56	8.58
Profile 2 (Tonga Shaibu) (N06° 51′11.5″ E011°23′06.05″ and elevation= 1435 m)								
Ap	0 – 54	54.24	11.28	34.48	5.31	24.50	8.91	9.99
Bt1	54 – 85	38.24	13.28	48.48	5.82	20.70	6.12	7.15
Bt2	85 – 126	45.24	9.28	45.48	5.78	19.00	7.41	8.45
Bt3	126 – 144	46.24	9.28	44.48	5.84	16.60	6.42	7.45
Bt4	144 – 160	44.24	9.28	46.48	5.80	15.40	5.95	6.96
Profile 3 (Dembe) (N06°45′05.30″ E011°20′02.7″ and elevation= 1275 m)								
Ap	0 – 30	28.88	23.28	47.84	6.24	17.80	7.00	8.15
A	30 – 39	74.88	11.28	13.84	6.17	11.00	6.47	7.56
AB1	39 – 49	52.88	23.28	23.84	6.16	15.60	6.05	7.10
AB2	49 – 60	76.88	11.28	13.84	6.14	18.40	6.12	7.16
Bt	60 – 70	34.88	29.28	35.84	6.20	21.10	7.25	8.27
C1	70 – 83	82.88	5.28	11.84	6.16	13.40	5.32	6.32
C2	83 – 106	86.88	3.28	9.84	6.17	9.00	5.72	6.88
Profile 4 (Kune) (N06°43′24.4″ E011°21′56.7″ and elevation= 1271 m)								
Ap	0 – 32	65.80	10.00	24.20	5.88	21.50	5.85	6.91
A1	32 – 65	66.80	12.00	21.20	5.70	13.40	6.86	6.97
A2	65 – 90	69.80	11.00	19.20	5.68	13.20	5.45	6.49
A3	90 – 113	66.80	13.00	20.20	5.68	7.20	6.10	7.13
A4	113 – 138	72.80	14.00	13.20	5.71	12.00	6.21	7.25
Bt1	138 – 165	67.80	10.00	22.20	5.15	7.60	6.05	7.07
Bt2	165 – 200	63.80	13.00	23.20	5.16	7.20	5.44	6.51
Profile 5 (Mbanga) (N06°37′03.4″ E011°12′28.1″ and elevation= 1481 m)								
Ap	0 – 40	86.24	5.28	8.48	5.66	20.50	7.42	8.50
A	40 – 89	78.24	13.28	8.48	5.68	12.40	4.99	6.00
Bt1	89 – 122	58.24	17.28	24.48	5.68	9.40	4.66	5.64
Bt2	122 – 160	28.24	37.28	34.48	5.76	18.60	7.23	8.27
C	160 – 200	74.24	11.28	14.48	5.76	20.30	5.82	6.83
Profile 6 (Dung) (N06°40′34.1″ E011°18′27.4″ and elevation= 1272 m)								
Ap	0 – 25	65.24	18.28	16.48	5.75	11.80	5.67	6.73
Bt1	25 – 49	36.24	17.28	46.48	5.60	6.20	4.91	5.92
Bt2	49 – 130	30.24	9.28	60.48	5.55	2.40	4.58	5.60
Bt3	130 – 200	28.24	9.28	62.48	5.54	5.40	4.81	5.80

OC= organic carbon, TEB= total exchangeable bases, ECEC= effective cation exchange capacity

Table 1. *Physico-chemical properties of the soils of Mambilla Plateau (cont'd)*

Horizon	Depth (cm)	Sand	Silt	Clay	pH (H_2O)	OC (g/kg)	TEB	ECEC
		⟶	%	⟵			⟶cmol/kg	⟵
Profile 7 (Leme) (N06°45′15.1″ E011°12′34.6″ and elevation= 1539 m)								
A	0 – 11	74.24	11.28	14.48	5.73	36.00	8.61	9.69
Bt1	11 – 42	56.24	15.28	28.48	5.70	20.90	6.52	7.56
Bt2	42 – 71	56.24	13.28	30.48	5.67	18.20	7.60	8.65
Bt3	71 – 87	62.24	9.28	28.48	5.68	26.10	8.69	9.78
Bt4	87 – 120	64.24	9.28	26.48	5.66	20.30	6.59	7.62
C1	120 – 164	87.24	4.28	8.48	5.61	27.90	9.05	10.12
C2	164 – 200	89.24	3.28	7.48	5.63	33.30	9.17	10.28
Profile 8 (Yerimaru) (3N06°47′39.4″ E011°02′42.1″ and elevation= 1522 m)								
Ap	0 – 25	72.24	7.28	20.48	6.03	26.00	6.10	7.16
Bt1	25 – 45	48.24	9.28	42.48	5.98	11.80	8.16	9.30
Bt2	45 – 115	40.24	13.28	46.48	5.96	12.00	8.15	9.29
Bt3	115 – 132	38.24	13.28	48.48	5.92	12.00	6.95	8.04
Bt4	132 – 200	38.24	13.28	48.48	5.89	9.00	6.97	8.04
Profile 9 (Furumi) (N06°53′51.8″ E011°04′00.7″ and elevation= 1497 m)								
Ap	0 – 21	74.24	11.28	14.48	5.68	21.50	5.21	6.29
Bt1	21 – 35	48.24	9.28	42.48	5.78	24.50	6.13	7.23
Bt2	35 – 100	38.24	13.28	48.48	5.88	20.90	7.02	8.14
Bt3	100 – 140	48.24	13.28	38.48	5.89	16.60	5.25	6.32
Bt4	140 – 186	48.24	9.28	42.48	5.92	15.40	6.12	7.21
Bt5	186 – 200	46.24	9.28	44.48	5.92	6.40	6.09	7.19
Profile 10 (Nguroje) (N06°53′00.8″ E011°07′54.8″ and elevation= 1499 m)								
Ap	0 – 30	76.88	5.28	17.84	6.06	32.90	7.46	8.63
Bt1	30 – 62	54.88	9.28	35.84	6.10	27.70	7.26	8.41
Bt2	62 – 93	68.88	7.28	23.84	6.15	12.80	6.67	7.71
Bt3	93 – 122	36.88	17.28	45.84	6.17	14.40	6.61	7.64
Bt4	122 – 140	36.88	17.28	45.84	6.16	12.40	6.43	7.46
Bt5	140 – 180	42.88	13.28	43.84	6.19	7.40	5.62	6.65
Profile 11(NgelNyake) (N07°05′27.6″ E011°05′17.0″ and elevation= 1608 m)								
Ap	0 – 34	62.24	9.28	28.48	5.90	34.10	6.93	8.05
A	34 – 87	82.24	7.28	10.48	5.94	34.90	6.28	7.34
BA	87 – 114	62.24	9.28	28.48	5.94	24.20	6.25	7.32
Bt1	114 – 132	46.24	9.28	44.48	5.96	11.80	5.20	6.25
Bt2	132 – 158	46.24	9.28	44.48	5.95	9.40	5.13	6.16
Bt3	158 – 200	44.24	9.28	46.48	6.00	8.00	5.06	6.08
Profile 12 (Maisamari) (N07°10′16.1″ E011°05′09.0″ and elevation= 1440 m)								
Ap	0 – 20	76.80	11.00	12.20	5.74	26.40	6.44	7.57
A1	20 – 43	77.80	10.00	12.20	5.84	27.10	6.11	7.16
A2	43 – 84	74.80	12.00	13.20	6.32	18.00	6.57	7.70
A3	84 – 111	78.80	11.00	10.20	6.31	31.00	8.14	9.24
A4	111 – 174	78.80	10.00	11.20	6.15	33.70	7.37	8.41
AB	174 – 200	72.80	10.00	17.20	6.08	17.80	6.66	7.69

OC= organic carbon, TEB= total exchangeable bases, ECEC= effective cation exchange capacity

However, Abagyeh et al. (2019) found that the vertical translocation of clay through the processes of lessivage and illuviation may be responsible for the overall rise in clay content with profile depth. The Fig 2 shows the interaction between the particle size fractions.

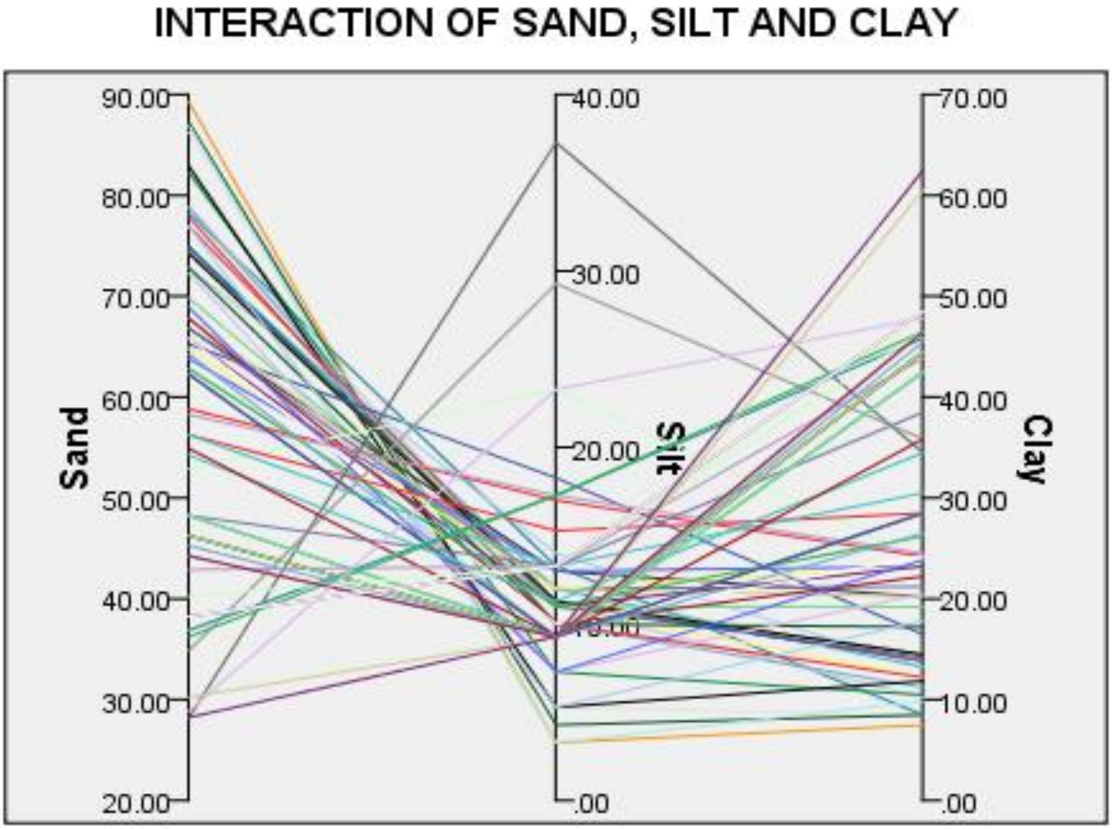

Fig. 2. *Interaction between the particle size distribution*

The findings (Table 1) indicated that the pH (H_2O) values of the soil varied from 5.15 to 6.32. Based on Chude et al. (2011) evaluations, the pH of the soil varied from slightly acidic to extremely acidic in the horizons of the profiles. Nevertheless, the soil pH result does not agree with the results of Hassan et al. (2015) in Nigeria's Plateau State's basaltic soils. An inconsistent increase or reduction in soil pH was noted as profile depth increased. On the soil of the Northern Nigerian savanna, researchers Domchang et al. (2014) and Sharu et al. (2013) noted similar pH levels and attributed the results to the parent material's composition, the leaching of basic cations from the soil surface to lower depths, and the frequent use of acid-forming fertilizers such as urea. The usage of ammonia-based fertilizer, frequent clearance of plant debris, and bush burning may all be contributing factors to the low pH in the majority of the profiles. The horizons' values for organic carbon content in the profiles varied from 2.40 to 36.00 g/kg. Based on Esu's (1991) evaluations, the profiles' organic carbon content ranged from low to high. Climate and leaching may have an impact on the rate of change of organic carbon over the horizons of the profiles. Numerous writers (Osujieke et al., 2019 and Fasina et al., 2015) have also noted low levels of organic carbon in savanna zone soils and have linked this to ongoing plant residue burning and cultivation, which has destroyed the majority of the organic components in the soil that would have contributed more to the soil organic matter.

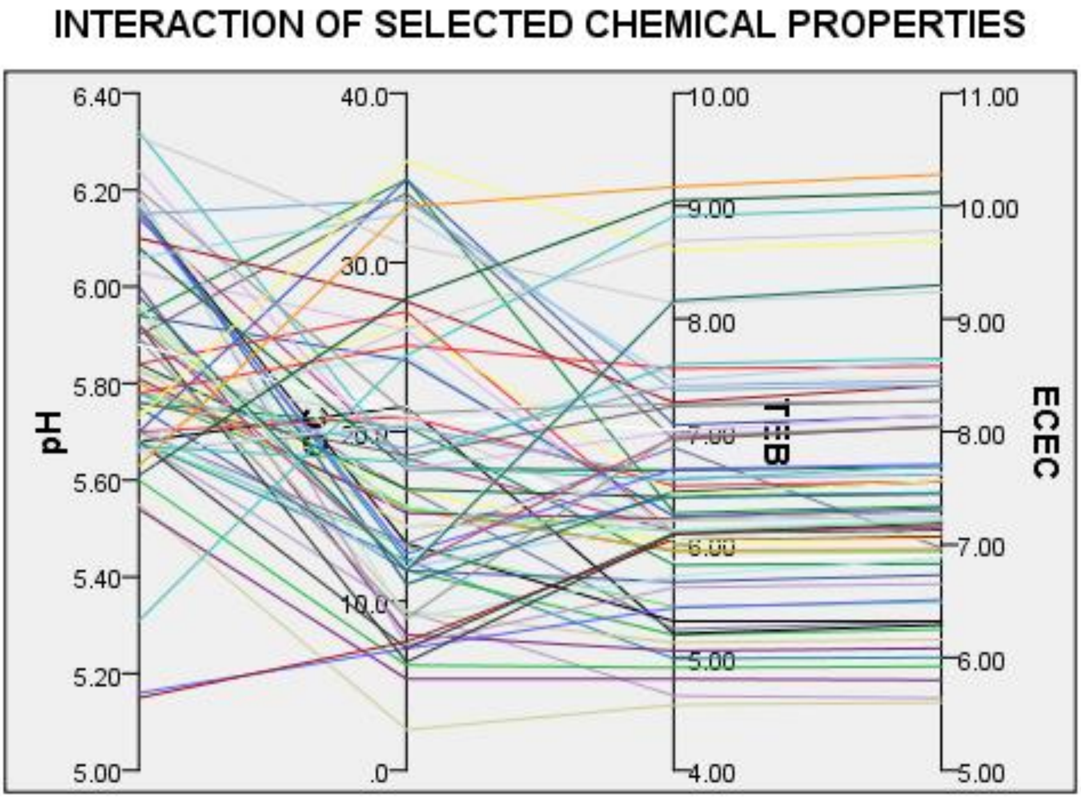

Fig. 3. *Interaction between Soil pH, OC, TEB and ECEC*

Total exchangeable base (TEB) values for the soil horizons varied throughout the profiles, ranging from 4.58 to 9.17 cmol kg^{-1}. Exchangeable bases were ranked low to high in every profile that was looked at, and they were found on the exchange complex in the following order: $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$. Abagyeh et al. (2019) results in the Guinea Savanna zone of Nigeria's soils were consistent with the profiles' total exchangeable basic cations. In the profiles, the soils' effective cation exchange capacity (ECEC) ranged from 5.60 to 10.28 cmol kg^{-1}. Based on the ratings provided by Esu (1991), the profiles' ECEC was classified as medium. The quantity of ECEC of soil is determined by the kind amount of clay and organic matter. The Fig 3 shows the interaction between soil pH, OC, TEB and ECEC.

The Table 2 displays the micronutrient data from the profile pits located at the Mambilla Plateau. Throughout the profiles, the soils' accessible zinc levels varied from 0.010 to 0.022 mg kg^{-1}. the range of zero. According to Tisdale et al. (1995) and Esu (1991), the critical limit of zinc was determined to be 8 mg kg-1 or less than 1.00 mg kg-1. It was discovered that the soils in the profiles' horizons deficient in zinc. Values for the Zn content fluctuated between 0.012 and 0.020 mg kg-1 throughout the profiles' surface horizons. Chesworth (1991) did note minimal mobility of zinc, though, as seen by the near values of the metal in the subsurface and surface soils. In all of the profiles, the available zinc did not exhibit a particular distribution trend with profile depth. Furthermore, the fact that Zn in some profiles declines with depth implies that plants might not have a Zn "store" on the lower surface. This is related to research done in the Guinea Savanna region of Nigeria's soils by Mustapha et al. (2011). The differences in Zn availability across and within the profiles' horizons are consistent with Jobbágy and Jackson's (2001) findings that micronutrients may be transported from one soil horizon to another by leaching.

Table 2. *Micronutrients of the soils of Mambilla Plateau*

Horizon	Depth (cm)	Zn	Mn	Cu	Fe
		mg/kg			
Profile 1(Jabu) (N06°53′52.8″ E011°24′13.9″ and elevation= 1567 m)					
Ap	0 – 29	0.017	0.026	4.2	0.37
Bt1	29 -48	0.016	0.025	3.6	0.32
Bt2	48 – 71	0.015	0.024	3.2	0.27
Bt3	71 – 86	0.014	0.022	3.1	0.25
Bt4	86 – 120	0.015	0.023	3.4	0.28
Bt5	120 – 180	0.015	0.023	3.8	0.26
Profile 2 (Tonga Shaibu) (N06° 51′11.5″ E011°23′06.05″ and elevation= 1435 m)					
Ap	0 – 54	0.013	0.026	3.6	0.27
Bt1	54 – 85	0.012	0.027	3.7	0.28
Bt2	85 – 126	0.014	0.028	3.8	0.29
Bt3	126 – 144	0.015	0.024	3.4	0.25
Bt4	144 – 160	0.013	0.023	3.3	0.24
Profile 3 (Dembe) (N06°45′05.30″ E011°20′02.7″ and elevation= 1275 m)					
Ap	0 – 30	0.016	0.025	4.3	0.38
A	30 – 39	0.018	0.027	3.8	0.29
AB1	39 – 49	0.017	0.026	3.6	0.28
AB2	49 – 60	0.014	0.023	3.5	0.25
Bt	60 – 70	0.013	0.021	3.3	0.23
C1	70 – 83	0.011	0.020	3.1	0.21
C2	83 -106	0.012	0.023	3.2	0.20
Profile 4 (Kune) (N06°43′24.4″ E011°21′56.7″ and elevation= 1271 m)					
Ap	0 – 32	0.017	0.026	4.2	0.38
A1	32 – 65	0.019	0.028	5.3	0.41
A2	65 – 90	0.018	0.027	5.2	0.40
A3	90 – 113	0.020	0.032	5.1	0.43
A4	113 – 138	0.016	0.025	4.8	0.38
Bt1	138- 165	0.018	0.027	4.6	0.39
Bt2	165 – 200	0.017	0.026	3.8	0.28
Profile 5 (Mbanga) (N06°37′03.4″ E011°12′28.1″ and elevation= 1481 m)					
Ap	0 – 40	0.017	0.028	3.9	0.29
A	40 – 89	0.014	0.025	3.6	0.25
Bt1	89 – 122	0.012	0.021	3.4	0.24
Bt2	122 – 160	0.013	0.020	3.3	0.22
C	160 – 200	0.015	0.024	4.4	0.25
Profile 6 (Dung) (N06°40′34.1″ E011°18′27.4″ and elevation= 1272 m)					
Ap	0 – 25	0.012	0.026	3.2	0.27
Bt1	25 – 49	0.013	0.024	3.3	0.25
Bt2	49 – 130	0.014	0.022	3.3	0.23
Bt3	130 – 200	0.013	0.020	3.0	0.21

Table 2.*Micronutrients of the soil of Mambilla Plateau (cont'd)*

Horizon	Depth (cm)	Zn	Mn	Cu	Fe
		⟶	⟶	mg/kg	⟵
Profile 7 (Leme) (N06°45′15.1″ E011°12′34.6″ and elevation= 1539 m)					
A	0 – 11	0.020	0.023	5.1	0.45
Bt1	11 – 42	0.018	0.025	4.3	0.38
Bt2	42 – 71	0.017	0.024	4.4	0.35
Bt3	71 – 87	0.019	0.027	4.2	0.36
Bt4	87 – 120	0.017	0.025	3.9	0.33
C1	120 – 164	0.019	0.026	4.8	0.37
C2	164 – 200	0.022	0.028	3.7	0.29
Profile 8 (Yerimaru) (3N06°47′39.4″ E011°02′42.1″ and elevation= 1522 m)					
Ap	0 – 25	0.019	0.030	3.9	0.35
Bt1	25 – 45	0.014	0.027	2.8	0.27
Bt2	45 – 115	0.013	0.028	3.2	0.25
Bt3	115 – 132	0.013	0.026	3.3	0.26
Bt4	132 – 200	0.017	0.024	3.1	0.21
Profile 9 (Furumi) (N06°53′51.8″ E011°04′00.7″ and elevation= 1497 m)					
Ap	0 – 21	0.012	0.028	3.8	0.31
Bt1	21 – 35	0.013	0.029	3.6	0.34
Bt2	35 – 100	0.010	0.027	3.4	0.27
Bt3	100 – 140	0.010	0.024	3.3	0.22
Bt4	140 – 186	0.012	0.021	3.5	0.26
Bt5	186 – 200	0.013	0.023	3.3	0.21
Profile 10 (Nguroje) (N06°53′00.8″ E011°07′54.8″ and elevation= 1499 m)					
Ap	0 – 30	0.014	0.023	3.8	0.35
Bt1	30 – 62	0.016	0.025	3.7	0.34
Bt2	62 – 93	0.018	0.027	3.6	0.31
Bt3	93 – 122	0.019	0.028	3.4	0.29
Bt4	122 – 140	0.017	0.026	3.2	0.28
Bt5	140 – 180	0.014	0.023	3.0	0.26
Profile 11(NgelNyake) (N07°05′27.6″ E011°05′17.0″ and elevation= 1608 m)					
Ap	0 – 34	0.018	0.031	4.5	0.38
A	34 – 87	0.019	0.034	5.3	0.39
BA	87 – 114	0.017	0.028	4.8	0.33
Bt1	114 – 132	0.013	0.027	4.6	0.27
Bt2	132 – 158	0.012	0.024	3.9	0.26
Bt3	158 – 200	0.013	0.020	3.4	0.24
Profile 12 (Maisamari) (N07°10′16.1″ E011°05′09.0″ and elevation= 1440 m)					
Ap	0 – 20	0.018	0.026	3.9	0.38
A1	20 – 43	0.017	0.026	4.0	0.38
A2	43 – 84	0.016	0.024	3.8	0.28
A3	84 – 111	0.022	0.029	4.2	0.43
A4	111 – 174	0.021	0.028	4.1	0.41
AB	174 – 200	0.019	0.026	3.8	0.39

The profiles of the Mambilla Plateau showed accessible manganese (Mn) contents ranging from 0.020 to 0.034 mg kg^{-1}. Mn levels in the surface horizons varied throughout the profiles, ranging from 0.023 to 0.031 mg kg^{-1}. According to Tisdale et al. (1995), the manganese concentrations in the soils in the profile horizons were below the critical threshold of 1–4 mg kg^{-1}. The measured Mn concentrations were below the range of 11.2 – 20.50 mg kg^{-1} discovered in the soils of the Northern Nigerian Savanna by Oyinlola and Chude (2010). In a similar vein, Rengel (2007) found that organic residue influences manganese's immediate and potential availability in soil.

The profiles' accessible copper (Cu) contents ranged from 2.8 to 5.3 mg kg^{-1} (Table 2). The range of 0.2 to 1.0 mg kg^{-1} given by Esu (1991) as the critical level was exceeded by the available Cu in the soils of the profiles as described, although Tisdale *et al.* (1995) suggested a critical value of 2.5 to 4.5 mg kg^{-1} for Cu. Cu levels in the surface horizons of the profiles ranged from 3.2 to 5.1 mg kg^{-1}. The previous findings of Hassan and Ogbonaya (2016) and Mulima et al. (2015) on the extremely low content of Cu for some sandy soils of the savannah biological zone are contradicted by the substantial Cu values found in all of the profile pits. Cu availability is not a characteristic of fertile soil. Despite the high Cu levels, they were within the predicted limits (< 100 mg kg^{-1}) for tropical soils and consistent with the results reported by Salisu et al. (2016). Both the parent materials and the use of agrochemicals may have an impact on the high content (Mustapha et al., 2017; Salisu et al., 2016). Cu may interfere antagonistically with macro- and micronutrients, causing harm to plant roots, thus it's important to be aware of any potential hazardous effects on plants (Silva et al., 2019). In different profiles, the distribution of copper along the depth of the profile followed an uneven pattern. According to Jiang et al. (2006), the variance can be linked to anthropogenic disturbance, leaching, and the accumulation of nutrients in the topsoil. Exchangeable bases may leach to lower depths, which could explain the rising Cu content with depth. Similar findings were achieved by Domchang et al. (2014) and Saddiq et al. (2008), who connected higher clay and exchangeable bases with Cu availability.

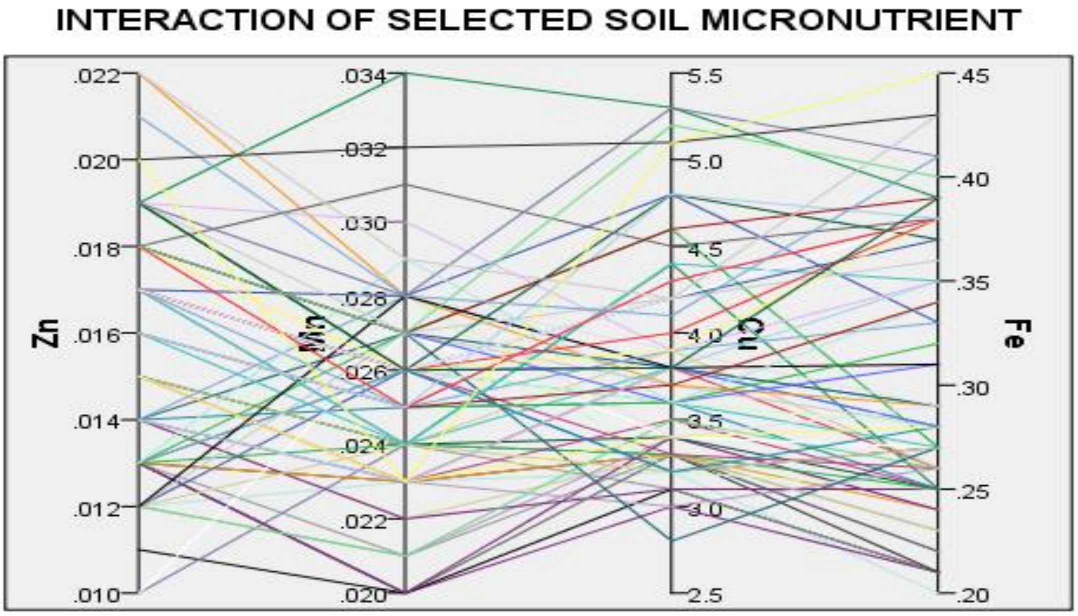

Fig. 4. *Interaction between the selected soil micronutrients*

Across the profiles, the soils' accessible iron (Fe) content ranged from 0.21 to 0.45 mg kg-1. The profiles' soils had less iron in them than the recommended thresholds of >2.5 mg kg-1 (Tisdale et al., 1995) and >4.5 mg kg-1 (Esu, 1991). On the other hand, the profiles' surface horizons showed Fe concentrations ranging from 0.27 to 0.45 mg kg-1. This result contradicts the findings on the soils of the Guinea savanna zone of Nigeria reported by

Mustapha et al. (2010) and Oyinlola and Chude (2010). Taking these essential limits into account, it was discovered that every profile pit was within the inadequate range. In every profile, the distribution of Fe content showed an uneven pattern down the profile depth. Thus, despite the fact that the soils under study were acidic, the low concentration of accessible iron raises the possibility that the soil's total iron content may be low. The Fig 4 shows the interaction between the studied micronutrients.

According to Rattan et al. (2008), the degree of variation in the soils' overall micronutrient content reflects the variety of parent materials from which they have come. The total micronutrient content of the soil is determined by parent material and pedogenic processes. The depletion of accessible micronutrients in soils is exacerbated by leaching loss of micronutrients, liming of soils, limited use of manures, and usage of excessive micronutrient fertilizers devoid of micronutrient additions (Saye et al., 2021). Higher micronutrient concentration was found on the soil surface, according to Ivana et al. (2015), who also linked the higher micronutrient content to increased crop residue decomposition and soil organic matter breakdown. Due to various soil and climatic factors, such as high rainfall, light texture, abundance of Fe and Al oxides, slow rate of organic matter decomposition, and high critical levels of nutrient availability, the deficiencies are even more severe in acidic soils (Saye et al.,2021; Singh, 2007). In most tropical soils, micronutrient deficiencies and soil acidity are the main factors limiting the productivity of a wide variety of crops (Singh, 2007; Kumar, 2001).

Table 3. *The relationship between micronutrient and selected soil properties*

Soil properties	Zn	Mn	Cu	Fe
	→ mg/kg ←			
Sand (g/kg)	0.473**	0.297*	0.431**	0.447**
Silt (g/kg)	-0.173	-0.251*	-0.162	-0.166
Clay (g/kg)	-0.479**	0.200*	-0.434**	-0.452**
pH(H_2O)	-0.001	-0.027	-0.214	-0.074
OC (g/kg)	0.434**	0.367**	0.403**	0.549**
TEB (cmol/kg)	0.445**	0.273*	0.188	0.344**
ECEC (cmol/kg)	0.424**	0.266*	0.153	0.323**

OC= organic carbon, TEB= total exchangeable bases, ECEC= effective cation exchange capacity, *= significant at correlation level (p<0.05), **= significant at correlation level (p<0.01)

The result as indicated in Table 3 showed that available Zn correlated positively and highly significant (r= 0.473, r= 0.434, r= 0.445, r= 0.424, p= 0.01) with sand, OC, TEB and ECEC while, it had a highly significant negative relationship (r= -0.479, p= 0.01) with clay. Available Mn had a positive significant relationship (r= 0.297, r= 0.200, r= 0.273, r= 0.266, p= 0.05) with sand, clay, TEB and ECEC while it had a highly significant relationship (r= 0.367, p= 0.01) with OC. Available Cu had a positive correlation (r= 0.188, r= 0.153) with TEB and ECEC while, it had a highly significant positive relationship (r= 0.431, r= 0.403, p= 0.01) with sand and OC. Available Fe had a high significant positive relationship (r= 0.447, r= 0.549, r= 0.344, r= 0.323, p= 0.01) with sand, OC, TEB and ECEC. Silt correlated negatively (r= -0.173, r= -0.251, r= -0.162, r=-0.166) with Zn, Mn, Cu and Fe. However, pH had a negative correlation with Zn, Mn, Cu and Fe. Similarly, Hassan et al. (2016) found that OC had a highly significant positive association with Cu and Mn, while Fe associated positively with silt and pH. However, pH linked adversely with Cu and Mn, although silt correlated negatively with Fe and Mn, according to prior research by Oyinlola and Chude (2010). The relationship's direction is indicated by the coefficient's sign. The coefficient is positive if both variables tend to rise or decrease together, and negative if one variable tends to increase while the other decreases.

Conclusions

Deficits in micronutrients in the soil have an impact on how well plants grow and develop. Therefore, to guarantee food and nutritional security, nutrient stress needs to be efficiently addressed. Because each crop has a unique micronutrient requirement and because micronutrients have a functional relationship with one another, it is exceedingly challenging to generalize soil management techniques for preserving sufficient levels of micronutrients in soils. The toxicity and inadequacy levels of micronutrients in soil vary little, therefore location-specific knowledge and management are crucial. Therefore, the application of micronutrient fertilizer, the addition of soil amendments, and the adoption of better plant types could all help to minimize micronutrient deficiencies.

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Agronomic and Economic Evaluation of Mineral Nitrogen Fertilizer and Farm Yard Manure on Production of Sesame (*Sesamum indicum* L.) in Southeast Ethiopia

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Abstract

Sesame is an important oil and cash crop produced in Ethiopia. However, its productivity is low due to inappropriate use of fertilizers. Therefore, a field experiment was conducted at Gode Polytechnic College demonstration site in 2022 cropping season to assess the effect of nitrogen (N) and farm yard manure (FYM) fertilizers on productivity of sesame. The experiment consisted of three levels of FYM (0, 5 and 10 t ha^{-1}) and four levels of N (0, 46, 69 and 92 kg N ha^{-1}). The experiment was laid out in RCBD in a factorial arrangement with three replications. The analysis showed that FYM and N significantly increased plant height, primary branches, capsules plant^{-1} and number of seed capsule^{-1}. Moreover, the interaction of N and FYM significantly affected days to flowering and maturity, 1000-seed weight, seed yield, biomass yield, and harvest index. Increasing the rate of FYM and N prolonged the days to flowering and maturity. The maximum 1000-seed weight (4.4) was recorded when 10 t FYM combined with 46 kg N ha^{-1}. Moreover, combination of 10 t FYM ha^{-1} with 46 kg N ha^{-1} resulted in maximum seed yield (1.84t ha^{-1}). Application of 10 t FYM ha^{-1} + 46 kg N ha^{-1} with net benefit (ETB 83,290.00 ha^{-1}) and marginal rate of return (410.04%) outperformed to ensure sustainable production. It could, thus, be concluded that application of 10 t FYM ha^{-1} + 46 kg N ha^{-1} is recommended for sustainable sesame production in study area.

Keywords: Economic benefit, farm yard manure, nitrogen, seed yield, sesame

Introduction

Sesame (*Sesamum indicum* L.) is an important oil crop in the world with high nutritive value (Weiss, 2000). The seeds are rich source of edible oil, protein, carbohydrate, vitamins, lignans, and lipids (Were et al., 2006). The oil is rich in polyunsaturated fat and contains low cholesterol, and the protein contains essential amino acids such as methionine and tryptophan (Ogundare et al., 2015).

Due to its high demand in the world, production of sesame is increasing (Langham and Wiemers, 2002). A number of countries produce sesame; Ethiopia is the seventh largest producer in the world (FAOSTAT, 2017). The major sesame producing regional states in Ethiopia are Tigray, Amhara, Oromia and Somali. However, due to various limitations sesame yield per unit is very low. There is a wide gap between the national average yield of sesame under rain-fed conditions (400-900 kg ha^{-1}) and under irrigated conditions (1,000-1,800 kg ha^{-1}) (EARO, 2004). Lack of harvesting and threshing machines, seed of improved varieties, and inappropriate use of pesticides by the producers are some of the constraints in sesame production (Tsehay, 2006). However, the main cause of the low productivity of sesame in Somali Regional State, Ethiopia is the inappropriate utilization of fertilizers (Mekonnen et al., 2016) and decline in soil fertility (Nwite et al., 2013) which is related to inherent low soil fertility or depletion through cultivation. The farmers in Somali regional state continuously cultivate with little or without application of the required nutrient to their farms. Thus, most of the arable lands are low in organic carbon and essential nutrients. This resulted in unbalanced soil nutrient composition that in turn led to a reduction in crop yield (Tonfack et al., 2009).

The low fertilizers application of the farmers to their farms was due to lack of awareness and /or they could not afford mineral fertilizers. In Ethiopia, mineral fertilizers such as urea-N are not affordable for poor smallholder farmers (Zerssa et al., 2021), their cost are increasing alarmingly. Studies showed that the price of the fertilizers increased by 170% in between 2020 to 2022 (MoA, 2022). This situation made the poor farmers apply mineral fertilizers below the recommended rate (Endale, 2010). Due to the application the lower rate of fertilizer and other agronomic factors the grain yield are lower as compared with the yields obtained from research stations (Zersa et al., 2021).

Growth, grain yield, seed quality of sesame is affected by fertilizer application either in mineral or organic form (Haruna, 2011). In sub-Saharan Africa (SSA) over 80% of the soils are nitrogen (N) deficient (Vanlauwe et al., 2015). As compared to the other nutrients, nitrogen contributes up to 50% to determine crop yield (Babajide and Oyeleke, 2014). Nitrogen is one of the nutrients that affect growth and yield of sesame. Nitrogen increase plant height, number of capsules per plant, and yield of sesame (Shehu et al., 2010). On contrary, increasing N application beyond the requirement decrease the seed quality such as seed oil content. Therefore, optimum N application is recommended to sesame production.

The soil type, climatic condition and the farming practices are the main factors to determine the rate of nitrogen fertilizer to be applied in specific area (Balasubramanian et al., 2004). Application of 100 kg DAP ha^{-1}and 50 kg urea ha^{-1}, which is total N amount of 41kg N ha^{-1}, gave the higher sesame grain yield in Humera, Ethiopia (HUARC, 2012). Barsan variety gave 2.08 t ha^{-1} grain yield using 46 kg N ha^{-1} in Gode under irrigation (Mekonnen et al., 2016).

Application of organic materials are important because they are source of organic carbon and essential nutrients which improves the fertility and physical properties of the soil (Murphy 2015) such as soil aeration, soil density which improves water holding capacity of soil for seed germination and root development (Zia et al., 1998). Organic manures are also preferred by poor farmers because they are easily available and affordable than chemical fertilizers (Alam et al., 2007). The communities in Somali Regional State are pastoralists and agro-pastoralists, thus there is abundance of FYM resource in the area. However, these resources are not being utilized properly by the community as fertilizer.

Application of organic manure alone will not satisfy the nutrient requirement of the crop. However, combined application of organic manure and mineral fertilizers increase the availability of nutrients (Iren et al., 2014). It implies the combined effect of organic and inorganic fertilizer increase productivity of crop and improves soil quality (Iren et al., 2014). Combined application of mineral N fertilizer and organic manure such as farm yard manure gave higher grain yield of sesame (Sahu et al., 2017). Thus, there is a need to investigate integrated effect of nitrogen fertilizer and organic fertilizer (FYM) on sesame production. Therefore, this study was initiated to investigate the effect of nitrogen fertilizer and farmyard manure on growth and yields of sesame.

Material and Methods

Description of the study area

The field experiment was conducted during 2022 cropping season under irrigation at Gode, Somali Regional State of Ethiopia, which is located at a distance of 1225 km south east of Addis Ababa, and about 580 km south of Jigjiga, the capital city of Somali Regional State. The experimental site is situated at the latitude of $5^0$57'N, longitude of 43°27'E and altitude of 320 meter above sea level. The annual average maximum and minimum temperatures are 35 and 23.6^0C, respectively. The mean annual rainfall of the area ranges from 150 to 340 mm which is not sufficient for rain-fed production (SoRSMA, 2013). The study area is characterized by high temperature, erratic rainfall, vast area of plain suitable for large scale irrigated agriculture and livestock (Gebremariam, 2005). The climate is characterized as arid agro-ecology. Rainfall pattern is characterized by main rainy season (*Gu*) that extends from April to June and the short rainy season (*Deyr*) from October to December. The farmers in the study area are mainly engaged in livestock production; but, they also produce fruits (papaya, mango, and banana), vegetables (tomato, onion and pepper), oil crop (sesame) and cereals (maize and sorghum) under irrigation, using the Wabe shebelle river.

Description of experimental materials

The sesame variety Barsan/ACC-00016 (1) was used as a test crop for its higher yield, locally adapted, and preferred by farmers in the area. Barsan variety was released in 2010 by Gode Pastoral and Agro Pastoral Research Center (GoPARC/SoRPARI) (EIAR, 2011). It is dominantly used in the area. It has brown seed, flowering of 50-60 days, and maturity of 80-90 days. Urea ($CO([NH_2]_2)$ (46% N) was used as a sources of nitrogen fertilizer (N). Farmyard manure (FYM) was used as a source of organic fertilizer which is abundantly available locally. The collected FYM had organic carbon content of 5.87% and total nitrogen 1.49%.

Treatments and experimental design

In this study, a factorial combination of three levels of FYM (0, 5, and 10 t ha^{-1}) and four levels of N (0, 46, 69, and 92 kg N ha^{-1}) were used. A randomized complete block design (RCBD) was employed and the treamtents were replicated thrice. Thus, there were total of 3x4=12 treatment combinations and 12 x 3=36 plots.

Experimental procedure and field management

The land was ploughed by a tractor to a depth of 25–30 cm. After layout as per the specification, each plot was leveled and ridged manually. The treatments were assigned randomly to each plot within block. Each gross plot had an area of 2.4 m x 2.0 m (4.8 m^2). A distance of 1 m was left between plots and 1.5 m between blocks. There were 6 rows per plot spaced 40 cm each and inter plant spacing within the rows was 10 cm. The outer most one row on both sides of each plots and two plants from each end of rows were considered as border and were not used for data collection to avoid edge effects. Thus, the net plot size was 1.6 m x 1.6 m (2.56 m^2).

The seeds were sown by drilling in furrows at a depth of about 2.5cm to ensure adequate emergence and were thinned one week after emergence to maintain the recommended spacing of 10 cm intra row spacing when the seedlings attained about 15 cm height. Based on the treatments, well decomposed farmyard manure was applied to the experimental plots 3 weeks before sowing. Half of nitrogen as a form of urea was applied at sowing and the remaining nitrogen was top dressed at pre flowering stage of the crop. Based on the recommendation for sesame, all other agronomic practices were perfomred uniformly for each experimental plot (EARO, 2004). Harvesting was done at physiological maturity when leaves and stems tended to change from green to yellow color and the leaves began to fall from the plants and the bottom capsule started to open.

Soil sampling and analysis

Before planting a composite soil sample at a depth of 0-20cm, representing each plot was taken for determining the physiochemical parameters of the soil of the experimental site. Soil texture, soil pH, organic carbon, total N, available P were taken. To determine nutrient content of farmyard manure representative sample was taken by combining all manure samples on concrete pad mixing thoroughly. The well mixed manure sample was identified by quartering method to get representative sample. Representative samples were grounded to pass through a 0.2 mm sieve for analysis, and analyzed to determine organic carbon, and total N.

Data collection

Starting from date of sowing, days to flower initiation were taken when 50% of the plant population on the net plot area started to bear flower whereas number of days to physiological maturity was recorded when 90% of the plant population in net plot started to turn their leaves yellow, the leaves began to fall from the plants, ¾ capsules on the capsule zone had turned from milky white to an off-white color and lower most capsules started to open (Terefe et al., 2012). Phenological stages were determined by visual observation.

From five randomly taken plants in each net plot area, the height of the main stem was measured from the ground surface to the tip of the apex at the time of physiological maturity. Number of primary branches $plant^{-1}$ was also counted from five randomly taken plants at physiological maturity.

Yield and yield related traits

At physiological maturity number of capsules $plant^{-1}$ was counted from five randomly taken plants. To determine the number of seeds $capsule^{-1}$, the average seeds of three capsules (lower, medium and upper position on the plant) from each of five plants were counted. Thousand seed weight (g) was determined from the count of 1000 seeds after sun drying by using sensitive balance. The aboveground dry biomass yield was recorded from net plot area by weighing with spring balance and converted into tons (t) ha^{-1}. Seed yield from each net plot area was recorded and converted into tons (t) ha^{-1}. Harvest index was determined by dividing the grain yield with total biomass.

Economic analysis

Partial budget analysis is a method of organizing experimental data about the cost benefit of some changes (CIMMYT, 1988). To reflect the difference between the experimental yield and the yield the farmers could obtain, the actual yield produced under different treatments was reduced downward by 10% (CIMMYT, 1988). To show the net benefit (NB), the total variable cost was subtracted from the gross benefit. To select potentially profitable treatments, the dominance analysis procedure was applied as described in CIMMYT (1988). The marginal rate of return (MRR) was computed as changes in NB divided by changes in cost. A dominance analysis was done by listing the treatments in order of increasing total variable costs. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary is dominated (D). The cost was calculated for FYM and urea fertilizer which was ETB 200 and 7000 for each 100 kg, respectively. The application cost of FYM ETB 10,000 birr per a truck (with capacity of carrying 10t) of FYM regardless of the amount to cover one hectare of land. The transportation cost to the field was ETB 100 per 100 kg FYM and ETB 500 per 100 kg urea. The local market price of sesame seed at the time of harvest was ETB 8000 per 100 kg.

Statistical data analysis

The data collected was subjected to the analysis of variance (ANOVA) appropriate to the design using SAS Software. The mean separation was performed using LSD at 0.05 level of probability.

Results and Discussion

Physico-chemical properties of the experimental site

The experiment was conducted from October to December, 2022 cropping season under irrigation condition. The experimental site soil analytical results indicated that the soil pH is 7.95 showing moderately alkaline nature of soil (Hazalton and Murphy, 2007). The crop thrives best in soil pH ranging from 5.5 to 8, it implies soil pH of the experimental site was suitable for sesame production. The result of the soil analysis also shows that the soil of the research area can be classified as sandy clay loam that contain total N of 0.03% which falls in the very low range (< 0.05), 5.01 ppm available phosphorus also in the low range (5-10 ppm) and 0.8 % organic carbon which is in the low range (0.6-1.0%) (Hazelton and Murphy, 2007). It indicates that the soil in the study area is low in total N, available P, and organic carbon. Therefore, application of nitrogen fertilizer and farm yard manure the study area is crucial to increase the level of N and C in soil, respectively.

Crop phenology

The interaction effect of farmyard manure and nitrogen significantly ($P < 0.05$) and ($P < 0.01$) influenced days to 50% flowering and days to 90% physiological maturity of sesame, respectively (Table 1). Plants grown under the treatment combination of 0 kg N ha^{-1} and 0 t FYM ha^{-1} flowered earlier (29.66 days) than the rest of the treatments. However, the maximum days to 50% flowering (46.66 days) was recorded from plots that were treated with combination of 92 kg N ha^{-1} and 10 t FYM ha^{-1}. The results indicated a difference of about 17 days between the highest and the lowest number of days to flowering. The increment of days to 50% flower initiation with the increasing application rates of N might be due to the positive effect of N that may have stimulated growth and prolonged vegetative growth period, thus delaying the reproductive phase of plant (Khan et al., 2009). Days to maturity were prolonged in response to increased levels of FYM (farmyard manure) and nitrogen. Plants grown under the treatment combination of nil-nil nitrogen and FYM application matured earlier (83 days) than the rest. However, the most prolonged maturity time (105 days) was recorded from plots that were treated with 92 kg N and 10 t FYM ha^{-1}, which increased maturity time by about 27% as compared to 0kg N and 0t FYM ha^{-1}.

Table 1. *Interaction effect of farmyard manure and nitrogen on days to 50% flowering and days to 90% physiological maturity of sesame in 2022 cropping season*

FYM (t ha^{-1})	N (kg ha^{-1})	Days to 50% flowering	Days to 90% physiological maturity
0	0	29.66^{h}	83.00^{g}
	46	32.66^{g}	85.00^{fg}
	69	33.00^{fg}	85.33^{f}
	92	34.00^{g}	85.66^{ef}
5	0	34.33^{fg}	85.66^{ef}
	46	36.33^{e}	87.66^{de}
	69	37.33^{de}	87.66^{ed}
	92	38.66^{d}	89.33^{bc}
10	0	38.66^{d}	90.33^{bc}
	46	42.33^{c}	90.66^{bc}
	69	44.00^{b}	91.66^{b}
	92	46.66^{a}	105.00^{a}
LSD $_{(0.05)}$		1.54	2.18
CV (%)		2.45	1.45

Means in columns sharing the same letter(s) are not significantly different at 5% level of significance; LSD=Least Significant Difference; CV= Coefficient of Variation

Growth and yield components

The main effect of the farm yard manure and nitrogen was significant ($P < 0.01$) on the plant height and number of primary branches produced per plant (Table 2). The increase in plant height with increased farmyard manure levels would be attributed to favourable effect of farmyard manure in better availability of N and the enhancing effect of N on cell division and elongation then on vegetative growth.

Enhanced vegetative growth of sesame under the influence of nitrogen application was also observed by Sisay (2014). In case of nitrogen effect, the shortest plants (98.50 cm) were observed for plants grown at nil nitrogen (control) application, while the longest (121.44 cm) plants were observed from application of 92 kg N ha^{-1}.

Increasing the rate of manure supply significantly increased the number of primary branches produced per plant. This result indicated that manure application promotes vegetative growth and is in line with that of Girma (2015) who reported that application of farmyard manure significantly outperformed the control treatment in terms of number of branches per plant of sesame. When the rate of nitrogen was increased from 0 to 92 kg N ha^{-1}, the number of primary branches per plant increased significantly by about 42.16%.

The two fertilizers had significant ($P < 0.01$) main effects on the number of capsules produced per plant and seed per capsule (Table 2). The number of capsules per plant increased significantly with the increase in FYM rates. This is may be attributed to the positive effect of manure in supplying plant nutrients to the soil and its ability to improve the soil physico-chemical properties which enhances crop growth and development.

When the rate of nitrogen was increased from 0 to 46 kg N ha^{-1}, the number of capsule per plant increased significantly. However, this parameter reduced when the rate of nitrogen was increased above 46 kg N ha^{-1}. Application of 46 kg N ha^{-1} had resulted in about 29.39% higher capsules per plant over control treatment. This result is in line with Sisay (2014) who reported significant response of Barsan variety to number of capsules obtained up to 46 kg N ha^{-1}. Similarly, increasing the level of FYM increased the seed per capsule.

The highest number of seeds (64.22) per capsule was obtained with the application of 10 t FYM ha^{-1} which was statistically in parity with the application of 5 t FYM ha^{-1}. This indicated that farm yard manure supply had the most profound effect on increasing number of seeds per capsule. In response to increasing the rate of nitrogen number of seed per capsule increased. The seeds per capsule were higher with application of N, which may be attributed to more number of leaves and high nitrogen use efficiency and more interception of sun light and at the result more photo assimilates go to reproductive parts of the plant which is seed of sesame (Muhammad *et al.,* 2014).

Table 2. *Effect of farmyard manure (FYM) and nitrogen on plant height, number of primary branches per plant, capsule per plant and seed per capsule of sesame in 2022 cropping season*

Treatment	**Plant height (cm)**	**Branches plant^{-1}**	**Capsule plant^{-1}**	**Seed capsule^{-1}**
FYM rate (t ha^{-1})				
0	97.98^{b}	2.92^{c}	75.48^{c}	59.64^{b}
5	104.51^{b}	4.20^{b}	96.73^{b}	62.55^{a}
10	127.24^{a}	4.91^{a}	106.78^{a}	64.22^{a}
LSD $_{(0.05)}$	6.59	0.52	7.15	2.43
Nitrogen (kg N ha^{-1})				
0	98.50^{c}	3.32^{c}	74.15^{c}	58.68^{c}
46	109.04^{b}	3.72^{bc}	95.95^{b}	61.88^{b}
69	110.66^{b}	4.30^{ab}	95.48^{b}	61.88^{b}
92	121.44^{a}	4.72^{a}	106.40^{a}	66.10^{a}
LSD $_{(0.05)}$	7.61	0.60	8.26	2.81
CV (%)	7.1	15.5	9.1	4.7

Means in columns sharing the same letter(s) are not significantly different at 5% level of significance; LSD=Least Significant Difference; CV= Coefficient of Variation

The analysis of variance revealed that interaction effect of farmyard manure and nitrogen had significant ($P < 0.01$) effect on thousand seed weight (g) (Table 3). Plants grown under the treatment combination of 0 t FYM ha^{-1} and 0 kg N ha^{-1} produced the lowest thousand seed weight (1.86 g) (Table 3). However, the maximum thousand seed weight (4.40 g) was recorded when 10 t FYM ha^{-1} was combined with 46 kg N ha^{-1}. In response to increasing the rate of nitrogen from 0 to 46 kg N ha^{-1}, the 1000-seed weight was increased significantly. However, when the rate of nitrogen was further increased to 92 kg N ha^{-1}, the 1000 seed weight though was decreased but it was not significant (Table 3). This result might be attributed to the positive role of N in the physiology of the plant in cell elongation and encouraging aboveground vegetative growth, photosynthesis and ultimate partitioning of photosynthate to the seed.

Yield and harvest index

It is clearly evident from Table 3 the interaction effect of farmyard manure and nitrogen had significant influence on seed yield of the sesame crop. The results indicated that combined application of FYM at 10 t ha^{-1} with 46 kg N ha^{-1} gave maximum seed yield (1.84 t) which was statistically in parity with the combined use of FYM at 10 t ha^{-1} with 69 kg N ha^{-1}. It was also observed that the seed yield increased with the increase in FYM application up to 46 kg ha^{-1} nitrogen rate. It was also revealed that the maximum yield has already reached at 46 kg N ha^{-1} showing that there was no need to apply 69 and 92 kg N ha^{-1} in sesame in the study area. The lowest seed yield (0.58 t ha^{-1}) was recorded from the control treatment. Thus, the seed yield was increased by 217%, due to combined application of 10 t FYM ha^{-1} with 46 kg N ha^{-1} over control treatment.

Table 3. *Interaction effect of farmyard manure (FYM) and nitrogen (N) rates on thousand seed, grain yield, biomass, harvest index of sesame in 2022 cropping season*

FYM (t ha^{-1})	N (kg ha^{-1})	1000 seed weight (g)	Grain yield (t ha^{-1})	Biomass (t ha^{-1})	Harvest index
0	0	1.86^{d}	0.58^{g}	4.09^{e}	0.14^{e}
	46	3.73^{bc}	1.33^{de}	4.18^{e}	0.31^{a}
	69	3.60^{c}	1.20^{ef}	4.21^{e}	0.28^{ab}
	92	3.60^{c}	1.11^{f}	5.28^{d}	0.21^{cd}
5	0	3.56^{c}	1.34^{de}	5.51^{d}	0.24^{bc}
	46	3.83^{bc}	1.39^{de}	7.08^{c}	0.19^{d}
	69	3.60^{c}	1.39^{de}	7.98^{bc}	0.17^{de}
	92	3.60^{c}	1.45^{cd}	8.35^{ab}	0.17^{de}
10	0	3.93^{b}	1.36^{de}	4.93^{de}	0.28^{ab}
	46	4.40^{a}	1.84^{a}	8.46^{ab}	0.21^{cd}
	69	3.60^{c}	1.73^{ab}	8.64^{ab}	0.20^{d}
	92	3.60^{c}	1.63^{bc}	9.05^{a}	0.18^{de}
LSD$_{(0.05)}$		0.30	0.19	0.94	0.1
CV (%)		5.0	8.3	8.6	12.9

Means in columns and rows sharing the same letter(s) are not significantly different at 5% level of significance; LSD=Least Significant Difference; CV= Coefficient of Variation

The analysis of variance showed that the interaction effect of farmyard manure and nitrogen had significant ($P < 0.01$) effect on biomass and harvest index (Table 3). Plants grown under the treatment combination of 0 t FYM ha^{-1} and 0 kg N ha^{-1} produced the lowest biomass yield (4.09 t). However, the maximum biomass yield (9.05 t) was recorded when 10 t FYM ha^{-1} was combined with 92 kg N ha^{-1}. Biomass yield increased over control treatment by about 121.27% when 10 t FYM ha^{-1} was combined with 92 kg N ha^{-1}. The significantly higher harvest index (0.31) was obtained when 46 kg N ha^{-1} was applied alone than the other interactions. The significant decrease in harvest index at the highest nitrogen application rate (92 kg N ha^{-1}) than 46 kg N ha^{-1} in the absence of FYM might be due to contribution of nitrogen in enhancing more the vegetative growth and thus lower photo assimilate production and its ultimate partitioning into stover compared to partitioning in seed that proved detriment to seed yield. At the end, the grain produced at the levels of nutrients application was not high enough to increase the harvest index.

Economic Analysis

As shown in table 4, the result of partial budget analysis revealed that the highest net benefit (ETB 86,476.00 ha^{-1}) and MRR % (468.19) was obtained from 0 t FYM + 46 kg N ha^{-1} followed by the net benefit (ETB 83,290.00 ha^{-1}) and MRR % (410.04) from treatment 10 t FYM + 46 kg N ha^{-1}. The highest marginal rate of return was recorded from nil application of FYM with 46 kg N ha^{-1}. However, application of FYM is crucial to ameliorate the soil physical, chemical and biological properties the degraded soil thereby ensure sustainable sesame production in the area.

Table 4. *Partial budget for farmyard manure and nitrogen application in sesame at Gode in2022 cropping season*

Treatment (FYM t + N kg ha^{-1})	**Average yield (kg ha^{-1})**	**Adjusted yield (kg ha^{-1}) (90%)**	**Gross benefit (ETB ha^{-1})**	**Total variable cost (ETB ha^{-1})**	**Net benefit (ETB ha^{-1})**	**Marginal Rate of Return (MRR) (%)**
0+0	583.30	524.97	41997.60	0.00	41997.60	-
0+46	1333.00	1199.70	95976.00	9500.00	86476.00	468.19
0+69	1207.00	1086.30	86904.00	14250.00	72654.00	D
0+92	1111.30	1000.17	80013.60	19000.00	61013.60	D
5+0	1342.70	1208.43	96674.40	25000.00	71674.40	177.68
5+46	1395.00	1255.50	100440.00	34500.00	65940.00	D
5+69	1391.00	1251.90	100152.00	39250.00	60902.00	D
5+92	1454.70	1309.23	104738.00	44000.00	60738.00	54.25
10+0	1369.00	1232.10	98568.00	40000.00	58568.00	D
10+46	1844.30	1659.87	132790.00	49500.00	83290.00	410.04
10+69	1737.00	1563.30	125064.00	54250.00	70814.00	D
10+92	1632.30	1469.07	117526.00	59000.00	58526.00	D

Therefore, the application of 10 t FYM + 46 kg N ha^{-1} with MRR % (410.04) is recommended in the test area. It indicates that each Birr 1.00 investment in sesame production, the producer can obtain Birr 1.00 and additional Birr 4.10. Based on this analysis it is advisable to apply the combination of 10 t FYM and 46 kg N ha^{-1} for this specific area to get more economic benefit.

Conclusion

The soils in the study area were low in nitrogen (N), phosphorous (P) and organic C, therefore, application of inorganic and organic fertilizer (such as farm yard manure) is advisable in the area. The community in the area are pastoralist and agro-pastoralists, thus they practice mixed farming (crop production and livestock rising). Thus, farm yard manure (FYM) is accessible and can be used to amend the degraded soil. The FYM apart from increasing crop yield could improve the soil physical, chemical and biological properties. Therefore, combined application of farm yard manure and nitrogen at rate of 10 t FYM and 46 kg N ha^{-1} is the optimum level for maximum yield with marginal rate of return (410.04 %). It indicates that each Birr 1.00 investment in sesame production, the producer or the farmer can obtain Birr 1.00 and additional Birr 4.10. Thus, the rate 10t FYM with 46 kg N ha^{-1} was found economically optimum rate to ensure sustainable sesame production in test area and in area with similar agro-ecology.

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Immobilization of Copper and Fluoride in Soils: Uptake by Chinese Cabbage

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Abstract

Elevated concentrations of fluoride (F) and copper (Cu) in food substances cause health problems. Effects of Wood ash, Cattle manure and CAN+NPK on mobility and uptake of Cu and F by Chinese cabbage were explored. The soils in this study were collected from Arusha, Tanzania. The experiment was completely randomized design with four treatments, each replicated four times. Four Chinese cabbage seeds were sown in the sieved soil samples (1 kg) and sown in 1 L containers. The Chinese cabbage were irrigated daily and allowed to grow for six weeks, and harvested. Organic amendments decreased the soluble fractions of Cu and F in the soils and reduced their uptake by Chinese cabbage. For fluoride, although significant reductions were observed, the concentrations were still above the allowed concentrations for human consumption. The Wood ash treatment was generally the most effective treatment of all. It was revealed that $\log_{10}$ of Cu concentrations in Chinese cabbage was positively related with $\log_{10}$ concentration of F in the plants, elucidating that the presence of one contaminant will generally enhance the uptake of the other. It was concluded that the amendments reduced the possibility of contaminating the food chain by the two pollutants in the soils.

Keywords: uptake, amendment, organic, inorganic, contamination

Introduction

Pollution in agricultural soils has negative effects on productivity (Godson-ibeji and Chikaire, 2016) and poses negative effects to public health. Some of these pollutants, especially heavy metals are non-biodegradable; they therefore persist in the environment and therefore they pose long-term negative health effects to living organisms. For example, the uptake of F and Cu by humans has been associated with several health problems including fluorosis (Fordyce et al., 2007) and increased risk of hypertension (Bergomi et al., 1997), respectively.

In Arusha, Tanzania, majority of the people experience dental and skeletal fluorosis (Kaseva, 2006) because of the prolonged uptake of water with elevated quantities of fluoride. Apart from the uptake of fluoride through water, fluoride uptake through food substances contaminated with F can add to the total F uptake by humans. Thus, F content in food should be given due weight in assessing the total F uptake (Bhattacharya et al., 2017). Research information shows that the plant availability of F is inconsistent, with reports on high mobility, medium mobility, and immobility. This shows that F bioavailability is soil and or plant specific.

In Northern regions of Tanzania, F toxicity signs in human beings are ubiquitous. In Arusha, the levels of dental fluorosis observed is a result of uptake from water and food (Kaseva, 2006). According to (Kaseva, 2006), other food additives such as trona, which contain elevated quantities of F, may contribute to F intake by humans. Information on the contribution of drinking water on F toxicity to human beings is available; however, information on the F intake through food is scant in literature. Furthermore, much research has been carried-out on methods of removing F from the drinking water (Baunthiyal and Ranghar, 2015). Ways to immobilize F in soils and reduce its bioavailability to plants is inadequate (Baunthiyal and Ranghar, 2015).

Arusha region especially in the coffee growing areas face a problem of copper toxicity as a result of heavy and longtime use of copper based fungicides in controlling fungal diseases (Senkondo et al., 2015). Other sources of Cu in soils, in general include irrigation water (Omron and Nadeem, 2012). Scholars (Li et al., 2019) reported positive relationship between soluble F contents in the soils and total Cu load; and that Cu and F contents in maize and wheat roots increased with increased Cu contents in the soils. Very little is reported on the effects of multiple pollutions on the uptake by crops to ascertain whether the two pollutants are antagonistic or synergetic. The information will provide means of reducing the transfer of contaminants into the food chain. This will increase our understanding on the consequences of the occurrence of multiple contaminants on the uptake of both contaminants and to explore possibilities of immobilizing them in the soils in order to hinder their plant uptake.

Materials and Methods

2.1 Description of the study area

Soil samples used in this study were taken from Maji ya Chai Ward, Arumeru District in Arusha region, Tanzania. Arusha is well known for its high quantities of F in water and in soils; as a result, there has been a prevalence of dental fluorosis in the area. Coffee farms in the area have been treated with fungicides with copper as part of active ingredient to control fungal diseases and therefore elevated quantities of Cu have been encountered in coffee farms.

One soil sample was collected at 0 – 20 cm from a maize farm that had never received copper-based fungicides and two samples were collected from farms that received copper-based fungicides for a long time. The collected soil samples were taken to Ardhi University Environmental Science Laboratory for analysis and for green house experiments. The collected soil samples were dried for five days. The dried samples were passed through a 2 mm sieve after grinding.

2.2 Experimental design

The experimental design was a completely randomized with four replicates each. The soils described under 2.1 were treated with different amendments. These are; Cattle manure (60 g kg^{-1}), wood ash (10 g kg^{-1}) and NPK+CAN fertilizers. The treatments and descriptions are presented in Table 1. This experiment was carried-out in a greenhouse. About 4 Chinese cabbage seeds were sown in the sieved soil samples (1 kg) and put in 1 L containers. The vegetables were irrigated daily, allowed to grow for six weeks, and harvested.

Table 1. *Experimental treatments and description of soil categories*

Treatment No.	Treatment	Description of soil types	
		Soil type	Description
1	Soil type A - No amendment added	A	High Cu and F contents
2	Soil type A + 60g Cattle manure		
3	Soil type A + 10g Ash		
4	Soil type A + NPK +CAN		
5	Soil type B - No amendment added	B	Moderate Cu and High F contents
6	Soil type B + 60g Cattle manure		
7	Soil type B + 10g Ash		
8	Soil type B + NPK +CAN		
9	Soil type C - No amendment added	C	Background Cu and high F concentrations
10	Soil type C + 60g Cattle manure		
11	Soil type C + 10g Ash		
12	Soil type C + NPK +CAN		

2.3 Soil analysis

Soil pH was determined at 1:2.5 soil water ratio using HACH Sension, 378 with model sensors, 5191000. The 1:2.5 soil water ratio solution was used to determine Electrical conductivity (EC) using EC HACH Sension, 378 with model sensors, 51935-00-CND. The water and soil were shaken for two hours in a mechanical shaker and the pH and EC determined (ISRIC 2002.). Copper was extracted using two extractants, 0.01 M $CaCl_2$, which represents a soluble fraction and *aqua-regia,* which represents the total content (Houba et al., 2000). The Cu contents were determined using flame atomic absorption spectrometer (Analyst 100, PerkinElmer Bodenseewerk, Germany).

Total fluoride concentrations in the soil was measured (Ruan et al., 2003). In this method, 0.5 g of oven dried soil at 105^0C was taken in 50 mL beaker; and 25mL of NaOH solution was added (4.5 g of NaOH), and left for 2 hours to dissolve then stirred after 30 minutes followed by filtering. The solution was made to 50 mL mark with 2 M NaOH solution in a conical flask. About 25 mL of the solution were taken into a beaker and the total ion strength adjusting buffer (TISAB) was added followed by the determination of fluoride using a fluoride ion selective electrodes. Water soluble F was determined; 20 g of oven dried soil samples were taken into 50 mL beakers, and 20 mL of distilled water were added and left overnight. The suspension was filtered in a 50 mL volumetric flask and made to the volume with distilled water. Twenty five millilitre (25 mL) of the aliquot were transferred into a 50 mL beakers and the total ion strength buffer (TISAB) was added and F was analyzed using fluoride ion selective electrodes (Model 51928 Platinum series).

The analysis of water extractable fluoride was established by mixing 20 mL of de-ionized water with 20 g of pulverized and sieved through 2-mm nylon sieve soil sample in 100 mL beaker. The mixture was stirred and left to settle overnight, then filtered on whatman no. 42 filter paper in a 50 mL volumetric flask and then distilled water was added to 50 mL mark. Twenty five (25 mL) of the aliquot was mixed with TISAB and stirred. Fluoride content was measured using ion specific electrodes (Model 51928 Platinum series).

2.4 Analysis of plant materials

The determination of copper in plant materials was carried-out as follows: The harvested Chinese cabbage plants were air dried for eight days then oven dried at 70 °C. The dried and ground plant materials were passed through a 1 mm sieve. The sieved plant materials were mixed with concentrated Nitric Acid and heated at 150 °C for two hours. Hydrogen peroxide was added successively after every 30 minutes until a total of 4 mL was attained. The solutions were left to cool then filtered in 25 mL volumetric flasks. The solutions were made to the mark using 2 M HNO_3. The Cu contents were measured by AAS.

Fluoride in plant materials was determined (Yadav et al., 2012); 0.5 g of oven dried, grounded and sieved Chinese cabbage samples were put into 50 mL centrifuge tubes, and 25 mL of Conc. Nitric Acid were added then left overnight. The tubes were put in the water bath (80^{O}C) for four hours. The tubes were cooled then filtered on 0.45 µm filter membrane. Distilled water was used to fill up to 50 mL with distilled water in conical flasks. Then, 25 mL were taken into a 50 mL beakers and the total ion strength buffer was added and analyzed using fluoride ion selective electrodes.

Results and discussion

3.1 Effects of amendments on soil pH

Soils used in the study were all in the acidic range with low to high Cu contents and all had elevated quantities of F (Table 2).

Table 2. *Properties of soil types used in the experiment*

Soil Sample	pH	OC (%)	EC (µs/cm)	CEC (cmol kg^{-1})	Total Cu (mg kg^{-1})	Total F (mg kg^{-1})
Sample 1	6.1	1.30	1660	79.58	735	24312
Sample 2	5.18	1.03	2320	67.70	215	17521
Sample 3	6.12	1.49	1390	28.38	37	22820

In the present study, cattle manure, wood ash, and the NPK + CAN fertilizers ($p=0.05$) increased significantly the soil pH of all the three soil types as compared with the control treatments (treatments with no amendment addition) as detailed in Table 3.

For soil type 1, wood ash treated soils had the highest increased pH than the other amendments. There was no significant difference in pH alteration between Cattle manure and NPK + CAN amended treatments. For soil type 2, NPK + CAN treatment did not significantly increase the soil pH in comparison with the control treatment whereas Cattle manure and Wood ash significantly enhanced the pH in comparison with the control treatment. The effect of the amendments, Cattle manure and the Wood ash on pH changes was insignificant. For soil type 3, all the three amendments had significantly increased the soil pH in comparison with the control treatment. However, the effects on soil pH among the amendments were insignificant. Soil pH is the main driver of solubility of metals in soils (Najafi and Jalali, 2016) because it is the main determinant of metal and Fluoride speciation and mobility (Kumpiene et al., 2006). In all the three soil types, the Wood ash treatment had consistently the highest pH among the three amendments. This treatment (Wood ash) had the lowest Cu (see sections, 3.2 to 3.5). This shows that Wood ash is the most effective F and Cu immobilizer compared to the other amendments used due to its liming effect that raises the pH of an acidic or neutral soil. The liming effect is attributed to the presence of oxides, hydroxides, carbonates, and silicates containing calcium and other bases (Harden and Pitt, 2013).

Table 3. Variations of soil pH under different treatments

Treatment/ Parameter	Mean Soil pH (n=4)		
	Soil type 1	Soil type 2	Soil type 3
No amendment added	6.1^{c}	5.2^{b}	6.1^{b}
Soil + 60g Cattle manure	8.4^{b}	8.4^{a}	8.9^{a}
Soil + 10g Ash	10.4^{a}	8.9^{a}	9.6^{a}
Soil + NPK +CAN	7.9^{b}	6.69^{b}	8.2^{a}

The same letter in the same column are not statistically different according to Tukey's method ($p=0.05$)
The same number in the same row are not statistically significant ($p=0.05$)

3.2 Effects of amendments on F solubility

For soil type 1, results show that all the three amendments significantly ($p=0.05$) reduced the solubility of F (Table 4).

Table 4. *Soluble F contents (mg kg^{-1})*

Treatment/ Parameter	Mean Soil Soluble F (n=4) (mg kg^{-1})		
	Soil type 1	Soil type 2	Soil type 3
No amendment added	161^{a2}	93^{a3}	216^{a1}
Soil + 60g Cattle manure	94^{b1}	70^{a1}	81^{b1}
Soil + 10g Ash	71^{b1}	26^{b3}	63^{bc2}
Soil + NPK +CAN	49^{bc2}	$75^{a1,2}$	103^{c1}

The same letter in the same column are not statistically different according to Tukey's method ($p=0.05$)
The same number in the same row are not statistically significant ($p=0.05$)

The most reduced treatment for the soil type was NPK + CAN, followed by Wood ash and the Cattle manure was the least. The reduction in F solubility between the cattle manure and the wood ash treatments were not significant. For soil type 2, only wood ash amended soils significantly reduced the solubility of F and this can be a result of the elevated soil pH associated with the addition of the ash (Wambu et al., 2016). The F solubility for soil type 3 was reduced in all the treatments with the most reduced F concentration being the Wood ash treatment and then the Cattle manure, while the NPK + CAN treatment was the least reduced. The increased pH in the present study resulting from the addition of different amendments corresponded with the decreased F solubility (see Figure 1). Upon degradation, organic matter amendments produce negatively charged functional groups on their surface, for example –OH,–COOH, and–NH_2), which can be replaced by F− (Chen et al., 2010), thereby making the F^- immobile in soils.

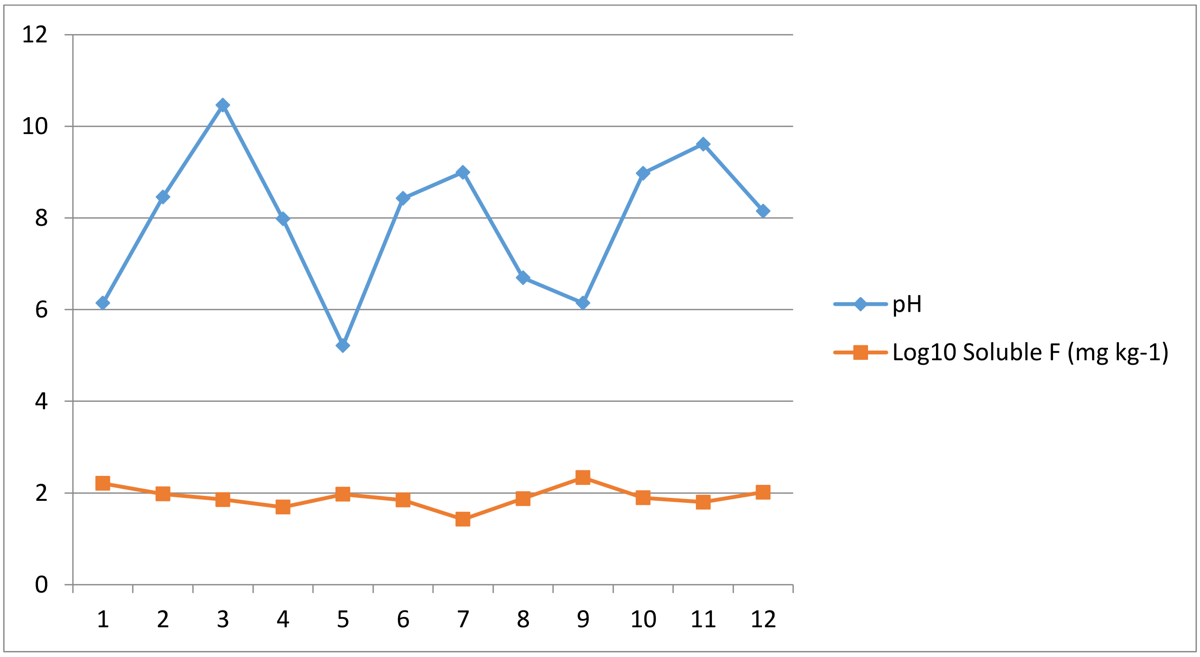

Figure 1. *Relationship between soil pH and solubility of F (mg kg^{-1}) in soils*

The reduced soluble F contents in the soil solution due to addition of the amendments implies that F–root contact has been significantly reduced. This is a very important process in detoxifying the soils because the water soluble F fraction is the one that is in contact with the biological system and is the one that is bioavailable. The bioavailable F fraction indeed poses a threat of contaminating the food web. Since these inorganic amendments contain essential elements for plants nutrition, it is quiet practical to use the materials as plant nutrients as well as F decontamination materials.

It is imperative therefore to integrate the inorganic fertilizers in soil fertility as well as in the environmental sanitation programs thereby offering a production system that would reduce excessive uptake of F. Further research therefore should be geared towards investigating the right rate of the fertilizer materials that are optimum for crop production and that would immobilize F to the levels that can reduce F uptake to acceptable levels. Since cattle manure also showed F immobilization potential, it is plausible to carry-out further experiments that would combine cattle manure and inorganic fertilizers to explore the possible synergy of the combined effects of the two types of amendments on F and Cu immobilization. It is also prudent to carry-out further studies on the long-term effects of these amendments on soil health and crop safety.

Table 5. *$CaCl_2$ extractable Cu (mg kg^{-1})*

Treatment/ Parameter	Mean soluble ($CaCl_2$) extractable Cu (n=4)		
	Soil type 1 (High Cu content)	Soil type 2 (Moderate Cu content)	Soil type 3 (normal Cu content)
No amendment added	4.8^{a1}	2.6^{a2}	1.6^{a2}
Soil + 60g Cattle manure	2.3^{b1}	$1.4^{b1,2}$	0.9^{ab2}
Soil + 10g Ash	1.1^{c1}	0.5^{b1}	0.4^{b1}
Soil + NPK +CAN	1.7^{b1}	$0.9^{b1,2}$	0.7^{b2}

The same letter in the same column are not statistically different according to Tukey's method (p=0.05)
The same number in the same row are not statistically significant (p=0.05)

3.3 Effects of the amendments on Cu solubility

For soil type 1 and 2, Cattle manure, Wood ash and the inorganic fertilizers significantly (p=0.05) reduced the $CaCl_2$-extractable Cu (Table 5) compared with the control treatments. For soil type 1, the wood ash treatment was the most immobilized one, whereas the Cu immobilization between NPK + CAN and Cattle manure treatments were not significantly different.

The concentration of $CaCl_2$-extractable Cu between control and the Cattle manure amended soils did not differ significantly for soil type 3. But the concentration of $CaCl_2$-extractable Cu for Wood ash or NPK +CAN amended soils was significantly lower than the control soils. However, the $CaCl_2$-extractable Cu among the three amendments in the three soil types was not significantly different except for the Wood ash treatment which had the lowest $CaCl_2$-extractable Cu concentration and therefore the wood ash was the most effective amendment in reducing Cu solubility as compared with the other amendments.

The increased soil pH (Table 3) observed resulting from the addition of the amendments matched with the decreased water soluble $CaCl_2$-extractable Cu (see Figure 2). Increased pH as a result of addition of the amendments may lead to Cu^{2+} hydrolysis forming $Cu(OH)^+$ and precipitating Cu as hydroxides ($Cu(OH)_2$) thereby making it insoluble and less bioavailable (Sebastia et al., 2007). The reduction in the metal solubility under elevated soil pH conditions can also be explained by increased adsorption capacity of the soils due to enhanced negative charges on soil colloids under alkaline conditions (Soltan and Ismail, 2019).

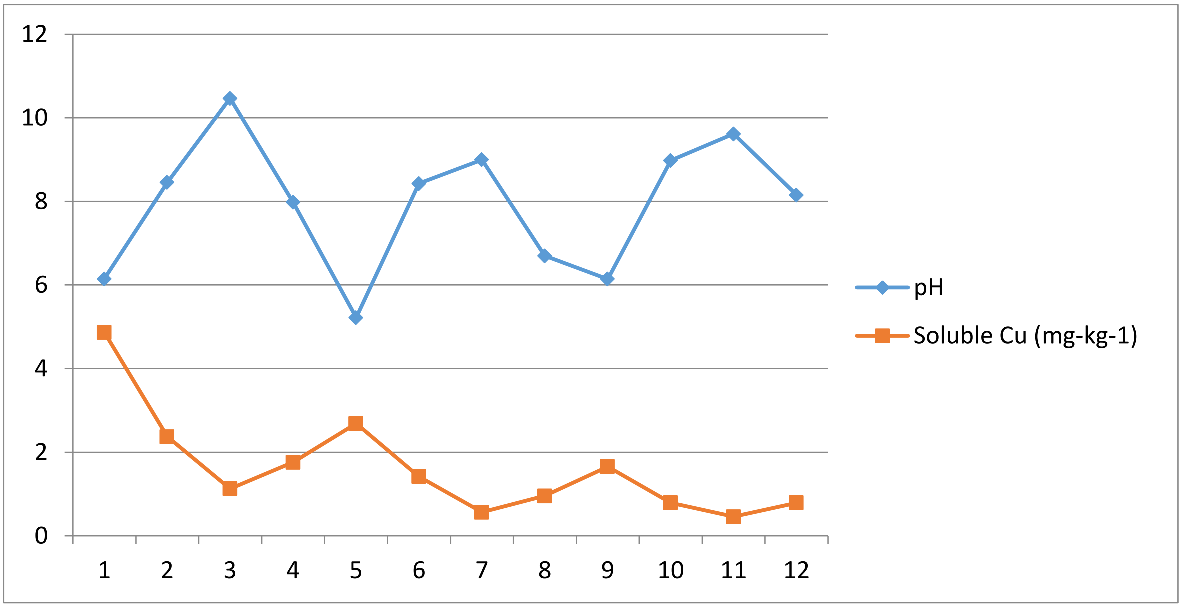

Figure 2. *Relationship between $CaCl_2$ extractable Cu and soil pH*

Elevated Copper contents in the soils (Table 2) were due to long-term use of copper-based fungicides. The farm that had background copper concentrations had never received copper containing fungicides. Continued use of fungicides therefore was the cause of the elevated Cu quantities observed. The soluble Cu contents encountered were very low (Table 5) as compared to the total Cu contents (see Table 2). Cu forms stable complexes with organic matter (Rieuwerts, 2007) and forms inner-sphere complexation culminating in its immobilization in the soils (Karlsson et al., 2006). For the un-amended treatments, it was found that soils with the highest total Cu load (Table 1) had higher soluble Cu than the moderately Cu contaminated soils and the soils with the background Cu concentrations (Table 5). Although soil pH is the major driver of Cu solubility in the soils (Najafi and Jalali, 2016), the pH values among the three soil types were not significantly different at $p=0.05$ (Table 3). Therefore, the higher concentrations of $CaCl_2$ extractable copper encountered in the soil can be attributed to the higher total Cu load in the soils due to use of copper-containing fungicides for a long time.

Inorganic fertilizers used in the present study contained Nitrogen, Phosphorus and Potassium (NPK), and Calcium Ammonium Nitrate (CAN). Phosphates are one of the decomposition products of organic matter, which can immobilize Cu in the soils. Cu may form stable complexes with humic substances, thereby reducing the solubility of Cu especially when high molecular weight compounds are formed (Liu et al., 2009) because Cu has strong affinity to specific sites of the organic matter molecules that lead to formation of stable complexes.

3.4 F Concentrations in plants

The concentration of F in Chinese cabbage plants encountered in the present study varied from 221 mg kg^{-1} to 3607 mg kg^{-1} (Table 6). There was a significant reduction in F uptake by Chinese cabbage as a result of addition of all the three amendments. For soil type 1, wood ash treatment had significantly lower F concentrations than the other two treatments (p=0.05) whereas the concentrations of F between Cattle manure and NPK+CAN were not significantly different. For soil type 3, the amendment that showed the highest reduced uptake of F was Wood ash, followed by NPK + CAN and the Cattle Manure was the least. In all the three soil types, Wood ash was the most effective F immobilizing treatment and the reduced uptake can be a result of liming effect of the Wood ash.

Table 6. *Concentrations of F in plants (mg kg^{-1})*

Treatment/ Parameter	Mean F in plants (n=4) (mg kg^{-1})		
	Soil type 1	Soil type 2	Soil type 3
No amendment added	1756a^{2}	1010^{a3}	3607^{a1}
Soil + 60g Cattle manure	697^{b1}	607^{ab1}	1561^{b1}
Soil + 10g Ash	363^{b1}	221^{b1}	524^{d1}
Soil + NPK +CAN	610^{b1}	552^{b1}	856^{c1}

The same letter in the same column are not statistically different according to Tukey's method (p=0.05)
The same number in the same row are not statistically significant (p=0.05)

The F concentration in Chinese cabbage observed was well above the normal F contents reported for several crops worldwide. The amendments added to the soils apart from reducing the soluble F contents in the soils (Table 4), deterred F uptake by Chinese cabbage by up to 6 fold. Wood ash and NPK + CAN treatments showed higher reduction in F uptake than the Cattle manure treated soils. This can be attributed to the presence of Calcium in the two amendments which have a liming effect that increased soil pH. Furthermore, Calcium containing compounds precipitate F in form of CaF_2 (Álvarez-Ayuso et al., 2011) in soils and reduce its availability to crops (Baunthiyal and Ranghar, 2015). Another mechanism of reduced F uptake by plants has been postulated (Ruan et al., 2004). They argue that calcium reduces cell membranes permeability of plants to Fluoride. That Calcium is an important constituent of plant cell walls and membranes and therefore its presence in cell walls reduces F uptake by plants due to reduced passage of F. Apart from precipitating F in the soils, Ca, which is present in plant cell walls acts as a buffer against F accumulation (Baunthiyal and Ranghar, 2015). The highest F concentrations in Chinese cabbage corresponded with the treatment with the highest concentrations of water soluble F (Tables 4 and 6) elucidating that the total F load determines the quantities of F to be taken by the Chinese cabbage.

3.5 Copper concentrations in plants

Amendments added to soils apart from decreasing the $CaCl_2$ extractable Cu, they as well significantly (p=0.05) deceased the uptake of Cu by the Chinese cabbage (Table 7). For soil type 1, the treatment that immobilized the Cu most was Wood ash followed by NPK + CAN and the Cattle manure was the least. In general, for soil type 1, the amendments immobilized the Cu by 9.2 fold (Wood ash), 7.1 (NPK + CAN) and 3.7 (Cattle manure). For soil type 2 and 3, a similar trend was observed but with different magnitudes of immobilization. For example, for soil type 2, Wood ash immobilized Cu by 9.5 fold (wood ash), by 3 fold (NPK + CAN) and 2.3 fold (Cattle manure). Whereas for soil type 3, wood ash immobilized Cu by 9 fold, NPK + CAN reduced Cu uptake by 3.8 fold and the cattle manure reduced Cu by 3 fold. The rate of immobilization by Wood ash was relatively the same for all the soil types, making it the most effective Cu immobilizer of the three amendments.

Table 7. *Concentrations of Cu in plants(mg kg^{-1})*

Treatment/ Parameter	Mean Cu in plants (n=4) (mg kg^{-1})		
	Soil type 1	Soil type 2	Soil type 3
No amendment added	34.1^{a1}	17.1^{a2}	13.5^{a2}
Soil + 60g Cattle manure	9.1^{b1}	7.4^{b1}	4.5^{b1}
Soil + 10g Ash	3.7^{c1}	1.8^{c1}	1.5^{b1}
Soil + NPK +CAN	4.8^{bc1}	5.8^{bc1}	3.6^{b1}

The same letter in the same column are not statistically different according to Tukey's method (p=0.05)
The same number in the same row are not statistically significant (p=0.05)

The highest mean Cu concentration observed in this study was 34 mg kg^{-1} and this happened in the soils with the highest concentrations of Cu without any amendments added. Several authors reported different critical levels of Cu in the plants above which toxicity is observed. The reported deficiency levels of Cu in plants ranges from 1 and 2 mg kg^{-1} and Cu toxicity was reported for concentrations in the plants above 20 mg kg^{-1} (Kabata-Pendias and Pendias, 2001). Therefore all the amended treatments had Cu concentrations well below the critical Cu concentrations in healthy plants.

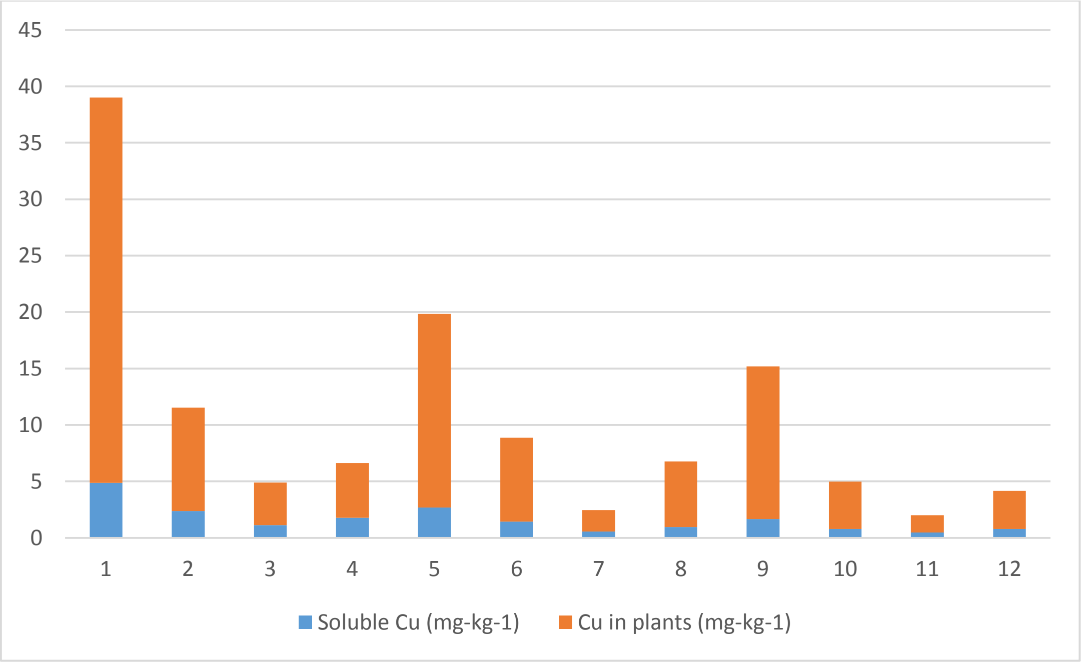

Figure 3. *Relationship between CaCl$_2$ extractable Cu and Cu concentrations in Chinese cabbage plants*

The contents of Cu observed in this study for the soils, which were highly contaminated surpassed the concentrations of Cu for normal plants. A decrease in Cu concentrations in Chinese cabbage plants grown on amended soils corresponded with a decrease in the contents of $CaCl_2$ extractable Cu. For example, the highly Cu contaminated soils (Figure 3) had the highest $CaCl_2$ extractable Cu contents and the highest concentrations of Cu in Chinese cabbage plants and vice versa. This shows that the amendments effectively reduced the uptake of Cu below toxic levels.

It is important to include these amendments in plant management programmes as fertilizer materials as well as detoxification materials. Importantly, further research should be carried to establish optimal levels that will ensure optimum reduction of Cu uptake as well as ensuring optimum nutritional and production requirements.

3.6 Relationship between concentration of F and Cu in soils and in plants

It was found that Cu concentrations in Chinese cabbage increased with an increase in $\log_{10}$ of soluble F in the soils (Figure 4), elucidating that F and Cu have a positive relationship. This relationship shows that the presence of one of the contaminants in soils enhances the uptake of the other thereby increasing a risk of contaminating the food web.

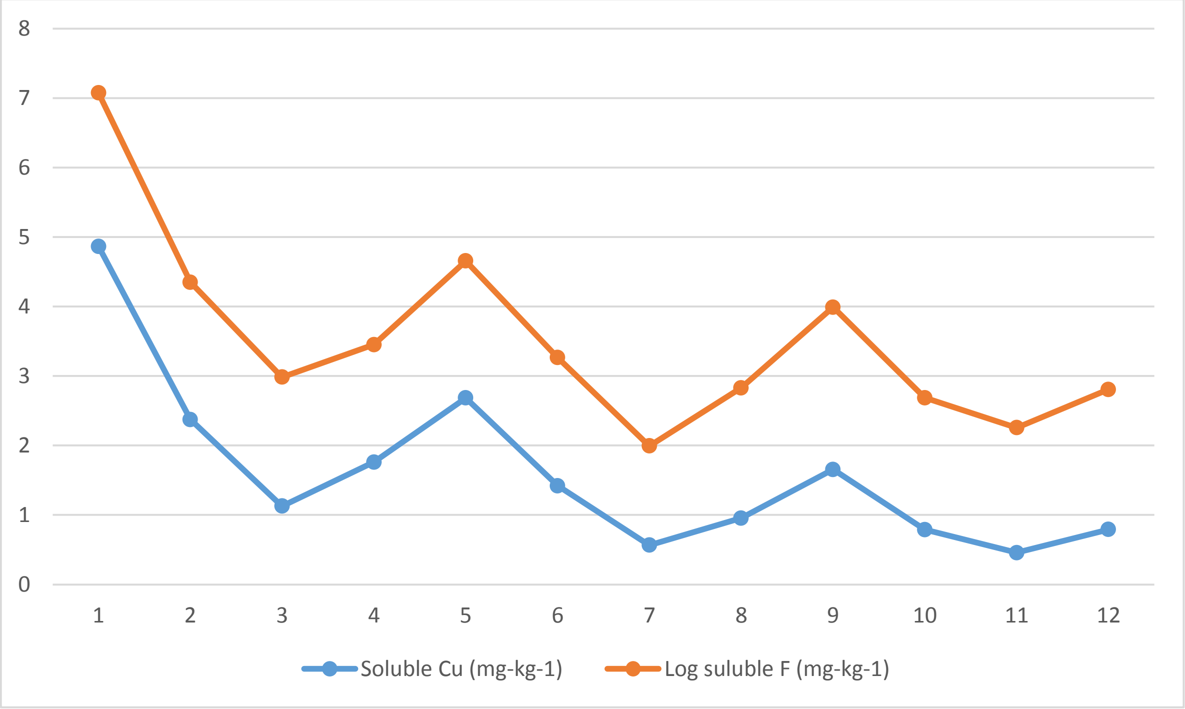

Figure 4. *Relationship between Soluble Cu (mg kg^{-1})and soluble F (mg kg^{-1})*

In the present study, it has been observed that the solubility and uptake of Cu or F is a function of the total Cu or F load in the soils. This means that with increased levels of either F or Cu contamination, the higher the uptake of the either pollutant, leading to elevated risks of polluting the food web (Figure 5).

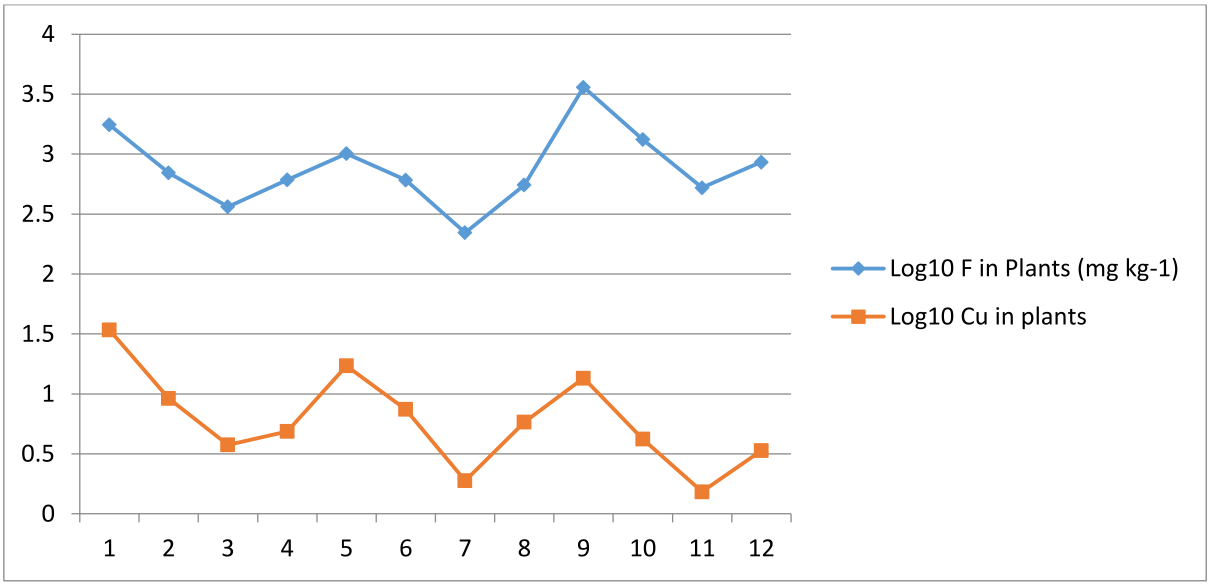

Figure 5. *Relationship between F concentrations in Chinese cabbage plants (mg kg^{-1}) and the concentrations of Cu (mg kg^{-1})*

Studies have revealed that the total Cu contents in the soils have a positive relationship with water soluble F and that Cu enhanced the solubility and accumulation of F in wheat leaves (Li et al., 2019). Furthermore, the authors reported that water soluble F fractions of some soils was positively related to the exchangeable fractions of Cu, showing that the soluble fractions of F can retain Cu in exchangeable fractions. The relationship between the soluble fractions of F and Cu in the soils can be attributed to the fact that F can form complexes with Cu (Cu-F complexes) and stay in a stable condition in aqueous solution (Manivannan et al., 2008). Very few literatures have explored the relationship between Cu and F in soils and in plants. It is important therefore to perform further studies in order to increase the understanding of the dynamics of these two pollutants in agricultural soils.

Conclusions

In conclusion, the organic amendments increased soil pH, and decreased the concentrations of Cu and F in the soils and consequently reduced their uptake by Chinese cabbage plants. Therefore, these amendments can reduce the possibility of contaminating the food chain as a result of the presence of the two pollutants in the soils. Although the amendments deterred the uptake of Cu and F by Chinese cabbage, the quantities of F encountered were well above the normal F contents in normal plants. Therefore, these soils should not be used to grow Chinese cabbage. However, the amendments successfully deterred the uptake of Cu by Chinese cabbage, and therefore the Cu concentrations did not surpass the normal F contents. Therefore, Cu in the amended soils does not pose a risk of polluting the food web.

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Effect of Land Use-Type on Soil Physical Properties Under Six Different Plantations

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Abstract

The effects of land use type (LUT) on the physicochemical properties of the soils of mango plantations (MPs), Neem plantations (NPs), arable farms (AFs), vegetable farms (FFs), flood plains (FPs), and residential areas (RAs) were evaluated from November-December 2022. Soil samples were collected from the ecological zone of Nigeria Sudan, which is Borno. To understand the drastic changes in land use types and their effects on ecosystems, investigations are required to explore the extent to which LUT affects soil properties in arid environments. Samples were collected at predetermined depths of 0-20 and 20-40 cm in all the LUTs. The samples were subjected to laboratory analysis and statistical tools such as Factorial (ANOVA) and Means Separations using (LSD) at a 0.05% probability level. Analysis of the effects of LUT and depth on soil particle size revealed that VFs had more sand and fewer FPs, with values of 70.30% and 55.30%, respectively; FPs had more silt and fewer AFs, with values of 30.833% and 14.583%, respectively; and AFs had more clay and fewer VFs, with values of 18.033% and 11.783%, respectively. There were no differences in the soil characteristics, and the soil textures were sandy loam for all the LUTs. BD, TP, WHC, MWD, θ, PR, and MC ranged from 1.37–1.46 g/cm^2, 44.67–48.5%, 21.23–29.70%, 0.077–0.1515 mm, 26.733–36.017°C, 20.833–29.333 N/cm and 0.1543–0.3303 cm3/cm3, respectively, with the greatest ranges found for VF-AF, AF-VF, MP-FP, RA-VF, VF-RA, VF-AF and RA-VF, respectively. Based on these findings, the 20-40 cm soil layer was best for all the LUTs. This study showed that land use type can affect soil physical properties. Therefore, vegetable farms and Neem plantations at depths of 20-40 cm were recommended for the study area.

Keywords: land, land use type, soil, soil physical properties, plantation

Introduction

Land use is a term used to describe the human use of land and is defined as the arrangements, activities, and inputs people undertake in a certain land cover type to produce, change, or maintain it (Ufot et al., 2016). It represents the economic and cultural activities (e.g., agricultural, residential, industrial, mining, and recreational uses) that are practiced at a given place (EPA, 2020). Successful agriculture requires the sustainable use of soil resources because soil can easily lose its quality and quantity within a short period for different reasons, such as intensive cultivation, leaching, and soil erosion (Kiflu et al., 2013). Agricultural practices, therefore, require basic knowledge of the sustainable use of land (Takele et al., 2014). The success of soil management in maintaining soil quality depends on understanding how the soil responds to agricultural practices over time (Duguma et al., 2010). Land use types are a process by which human activities transform the natural landscape, referring to how the land has been used, usually emphasizing the functional role of land for economic activities (Paul, et al., 2017). Land use types can affect several soil properties depending on the intensity and type of use, and some of the physical properties of soil may be modified (e.g., structure, consistency, bulk density, porosity, aggregate stability, moisture content, particle size and texture) (Paz González et al., 2014). The physical properties of soil include color, texture, structure, porosity, density, consistency, temperature, and air (Usman, 2013). The physical properties of the soil are very important for agricultural production and the sustainable use of soil. The amount and rate of water, oxygen, and nutrient absorption by plants depend on the ability of the roots to absorb the soil solution as well as the ability of the soil to supply it to the roots (Almendro et al., 2018). Information about the effects of different land use types on soil physical and chemical properties is crucial for best land management practices (Girma, 2020). Knowledge of soil properties is very useful for determining soil characteristics, quality, and productivity (Akinde et al., 2020). The information gathered in this study will provide useful feedback to farmers, extension agents, and the government on land use design and implementation. It is also expected that the results will be useful to government and extension service providers in planning, designing, and evaluating effective and efficient agricultural policies, programs, and projects at local, regional, and national scales for smallholder farmers in the semiarid tropics of Sub-Saharan Africa (Mzezewa et al., 2011). Understanding soil properties under different land use types is vital for determining the types of soil management practices that could be implemented by smallholder farmers to improve soil health as well as soil productivity. It is also important in addressing the issues of agricultural sustainability (Negasa et al., 2017). Inappropriate land use leads to the deterioration of potential productivity, including ecological functioning and ecosystem services (Alaboz et al., 2021). Soil properties can be influenced by long-term agricultural management practices, as described in the pedological literature (Vopravil et al., 2020). Land use types have long been considered among the many factors responsible for physical and chemical soil degradation (Fentie et al., 2020). This paper assesses the effect of land use-type on soil physical properties in Jere agricultural area of Borno State Nigeria.

Materials and methods

Study area

The study was conducted in Gongulong-Meyerari agricultural area located in Jere, local government of Borno State, Nigeria. The area is positioned along the coast of the Ngada River where vegetable crops are grown annually for commercial purposes (van Herk, 2012). The area falls within the 11.923100^{o}N and 13.221758^{o}E of Borno State (Figure 1). It is characterized by biannual mean rainfall and temperatures of 650mm and 32^{o}C respectively. The months of March and April are the hottest periods of the year, with monthly temperatures ranging between 30^{o}C and 40^{o}C. The volcanic and basement complex areas of the region have fertile clayey loamy soils in valley bottoms, but skeletal soils and rock outcrops occur along gentle and steep slopes (van Herk, 2012). The vegetation accomodated plants such as *Mangifera indica, Acacia nilotica, Acacia senegal*, *Acacia seyal*, *Azadirachta indica*, *Ziziphus* spp. and *Balanites aegyptiaca*.

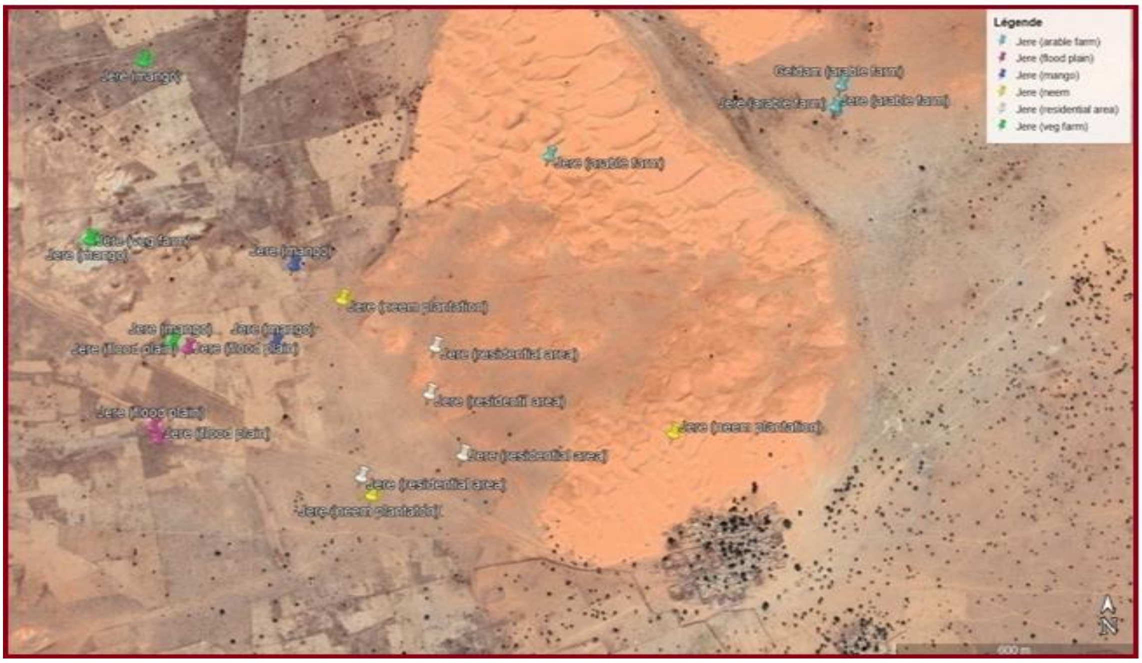

Figure 1. *Areal map of the study area*

Site Selection and Soil Sampling

The methodology consisted of primary recognition and pre-assessment site visits for defining land use types. A random-systematic method was used for soil sampling in key areas of each land use type in 2022. First, the study area was divided into six land use systems (residential land, arable farms, vegetable farms, floodplain land, mango plantations, and Neem plantations). For each land use, soil samples were obtained at a constant depth 0 - 40 cm at 20 intervals following a Z layout design. Approximately 1 kg of composite samples were collected from each land use and placed in polythene bags. For each adjacent land use, composite soil samples were collected 0 – 20 from random soil subsamples within 40 cm depth using a hand auger for four replications. For the determination of bulk density, thirty-six undisturbed soil samples were also collected using a core sampler at the site, and thirty-six samples were collected for each land use type.

Laboratory analysis

The soil particle size distribution was analysed using the hydrometric method (Bouyoucos, 1962). Soil bulk density (BD) was determined from undisturbed soil samples collected using a core sampler (Blake, 1986). Total porosity (TP) was calculated from the values of bulk density (BD) and particle density (PD) (Brady, 2008). The moisture content was determined using the gravimetric method (Black, 2005). Aggregate stability is an important property and can be measured as dry aggregate stability, and the mean weight diameter (MWD) is calculated by the method suggested by Yoder (1936) and Youker and McGuinness (1957). A concrete penetrometer is used to determine the penetration resistance of soil in fields (Biologydiscussion, 2020). The water holding capacity was determined according to the methods of Biologydiscussion (2020).

Results

Effects of land use type and depth on the soil particle size analysis

Table 1 gives the results of the effects of land use type and depth on the soil particle size analysis. There is inequality ($p \leq 0.05$) in the effects of land use type and depth on the soil particle size. Similarly, there was a significant difference in the effects of land use types on sand; the highest value was recorded for a vegetable farm, with a value of 70.30%, and the lowest value was obtained for a flood plain, with a value of 55.30%. However, there was no significant difference in the effects of depth on the sand; the highest value was recorded at a depth of 0-20 cm, with a value of 63.906%, and the lowest value was obtained at a depth of 20-40 cm, with a value of 63.667%, although there was numerical variation across the depths.

Table 1. *Effects of land use types and Depth on Particles size analysis Jere*

Land use types	Sand (%)	Silt (%)	Clay (%)	Textural class
Arable Farm	67.383^{a}	14.583^{c}	18.034^{a}	Sandy loam
Flood Plain	55.3^{b}	30.833^{a}	13.867^{b}	Sandy loam
Mango Plantation	66.133^{a}	21.667^{b}	12.2^{b}	Sandy loam
Neem Plantation	66.633^{a}	19.217^{bc}	14.15^{b}	Sandy loam
Residential Area	56.967^{b}	29.167^{a}	13.866^{b}	Sandy loam
Vegetable Farm	70.3^{a}	17.917^{bc}	11.78b^{b}	Sandy loam
LSD (0.05)	5.7721	5.1341	4.367	
SE±	2.8178	2.5064	1.864	
Depth (cm)				
0-20	63.906^{a}	21.961^{a}	14.133^{a}	Sandy loam
20-40	63.667^{a}	22.5^{a}	13.833^{a}	Sandy loam
LSD (0.05)	5.0803	5.0593	0.986	
SE±	2.4941	2.4838	0.579	

*=significant at 5% LSD= least significant difference and LUT= land use type

Nonetheless, there was a significant difference in the effects of land use types on silt; the highest value was observed on a flood plain, with a value of 30.833%, and the lowest value was obtained on an arable farm, with a value of 14.583%. There was no variation in the effects of depth on silt; the greatest difference was recorded at depths of 20-40 cm, with a value of 22.500%, and the lowest difference was obtained at depths of 0-20 cm, with a value of 21.961%. There was a significant difference in the effects of land use type on clay; the highest value was recorded for an arable farm, with a value of 18.033%, and the lowest value was obtained for a vegetable farm, with a value of 11.783%. There was no significant difference in the effects of depth on the clay content; the highest value of 14.122% was recorded at depths ranging from 0-20 cm, and the lowest value of 13.833% was observed at depths ranging from 20-40 cm. The textural class was sandy loam for all land use types.

Effects of land use type and depth on the soil physical properties of Jere

The results on the effects of land use type and depth on soil physical properties are presented in Table 2.

Table 2. *Effects of Land use types and Depth on Soil Physical Properties of Jere*

Land use types	Pb (g/cm^2)	%TP	%WHC	MWD (mm)	Temp (^{o}C)	P.R (N/A)	θv (cm^3/cm^3)
Arable Farm	1.4617^{a}	44.667^{d}	21.90^{bc}	0.0825^{cd}	35.517^{ab}	29.333^{a}	0.1563^{b}
Flood Plain	1.395^{cd}	47.333^{ab}	29.70^{a}	0.129^{7b}	33.983^{bc}	25.50^{a}	0.1938^{b}
Mango Plantation	1.4533^{ab}	45.00^{cd}	21.233^{c}	0.0743^{d}	30.267^{d}	25.333^{a}	0.1997^{b}
Neem Plantation	1.4167^{bc}	46.667^{bc}	24.05^{b}	0.1023^{c}	33.15^{c}	26.00^{a}	0.1692^{b}
Residential Area	1.43^{abc}	45.833^{bcd}	22.75^{bc}	0.077^{d}	36.017^{a}	29.167^{a}	0.1543^{b}
Vegetable Farm	1.37^{d}	48.50^{a}	22.583^{bc}	0.1515^{a}	26.733^{e}	20.833^{a}	0.3303^{a}
LSD Value	0.0424	1.6972	2.7199	0.0210	1.8213	15.072	0.0554
SE±	0.0207	0.8286	1.3278	0.0102	0.8891	7.3577	0.0271
Depth (cm)							
0-20	1.4617^{a}	44.667^{b}	35.517^{a}	0.1563^{b}	21.9^{b}	29.333^{a}	0.0825^{b}
20-40	1.395^{b}	47.333^{a}	33.983^{b}	0.1938^{a}	29.7^{a}	25.5^{a}	0.1297^{a}
LSD Value	0.0424	1.6972	1.8213	0.0554	2.7199	15.072	0.0210
SE±	0.0207	0.8286	0.8891	0.0271	1.3278	7.3577	0.0102

Pb=bulk density, TP=total porosity, WHC=water holding capacity, MDW=mean weight diameter, PR=penetration resistance, θv=volume moisture content, LSD=large difference and SE=standard error, LUT=land use type.

The results revealed a significant difference ($p<0.05$) in the effects of land use type and depth on the soil physical properties. There was a relationship in the effects of land use type and depth on the bulk density; the highest values were recorded at arable farms and depths of 20-40 cm (1.4617 g/cm^3 and 1.4489 g/cm^{3,} respectively), and the lowest values were obtained at vegetable farms and depths of 0-20 cm (1.3700 g/cm^2 and 1.3933 g/cm^{2,} respectively). The bulk density in undisturbed soils ranges from approximately 1.0 to 1.45 g/cm^3, which is normal for sandy loam soil and increases with depth in the soil profile (Kozlowski 1999). However, there was no relationship in the effects of land use type and depth on the total porosity; the highest values were recorded at vegetable farms and depths of 0-20 cm (48.500% and 47.444%, respectively), and the lowest values were obtained at arable farms and depths of 20-40 cm (44.667% and 45.222%, respectively).

In general, the total porosity of unconsolidated materials ranges from 0.25-0.7 (25%-70%). Coarse-textured soil materials such as gravel and sand tend to have a lower total porosity than fine-textured soils such as silts and clays. The total porosity in soils is not constant because the soil, particularly clayey soil, alternately swells, shrinks, compacts, and cracks (Yu *et al*., 1993).

Likewise, there was dissimilarity in the effects of land use type and depth on the water holding capacity. The highest values were recorded for the flood plain and at depths of 0-20 cm (29.700% and 25.011%, respectively), and the lowest values were obtained for the mango plantation and at depths of 20-40 cm (21.233% and 22.394%, respectively). There was a high variability in the effects of land use type and depth on the mean weight diameter; the greatest difference was recorded at vegetable farms and depths of 0-20 mm (0.1515 mm and 0.1094 mm, respectively), and the lowest difference was observed at mango plantations and depths of 20-40 cm (0.0743 mm and 0.0964 mm, respectively).

Soils with MWDs greater than 0.25 mm are considered good for crop production (Phogat, 2016). The results also show that there was a inconsistency in the effects of land use type and depth on the soil temperature; the highest values were recorded in the residential area and at depths of 0-20 cm (36.01°C and 33.77°C, respectively), and the lowest values were obtained at the vegetable farm and at depths of 20-40 cm (26.73°C and 31.45°C, respectively).

The daily soil temperature for clayey soil ranges from 27.7–28.90°C, with a simple mean of 28.3°C; the daily soil temperature ranges from 28.2–29.10°C for sandy soil and from 28.3–34.00°C for loamy soil. The mean temperature for all soil types is 29.70°C, indicating that these soils are favourable for farming (Nwankwo, 2012). In the same way also, there was a differences in the effects of land use type and depth on soil penetration resistance; the highest values were recorded at arable farms and depths of 0-20 cm (29.333 and 37.167, respectively), and the lowest values were obtained at vegetable farms and depths of 20-40 cm (20.833 N/A and 14.889 N/A, respectively).

Likewise, there was a variations in the effects of land use type and depth on the soil moisture content; the highest values were recorded at vegetable farms and depths of 20-40 cm (0.3303 cm^3/cm^3 and 0.2365 cm^3/cm^{3,} respectively), and the lowest values were obtained at arable farms and depths of 0-20 cm (0.1543 cm^3/cm^3 and 0.1647 cm^3/cm^{3,} respectively). The volumetric soil moisture content remaining at field capacity is approximately 0.15 to 0.^{25} ^{cm3}/cm^3 for sandy soils, 0.35 to 0.45 cm^3/cm^3 for loam soils, and 0.45 to 0.55 cm^3/cm^3 for clay soils.

Interaction effects between land use type and depth on the soil physical properties

The results of the interactive effects between land use type and depth on soil physical properties are presented in Table 4. The results revealed a significant difference ($p<0.05$) in the interactive effects of land use type and depth on the soil physical properties of Jere. There was a variation in the interactive effects of land use type and depth on the bulk density, total porosity and water holding capacity. The highest values were recorded at the Mango Plantation site at depths ranging from 20-40, at the Vegetable Farm site at depths ranging from 0-20 and at the Flood Plain site at depths ranging from 0-20, with values ranging from 1.50 g/cm2, 49.00% and 30.53%, respectively, and the lowest values were obtained at the Vegetable Farm, Mango Plantation site at depths ranging from 20-40, 0-20 and Vegetable Farm site at depths ranging from 20-40, with values ranging from 1.38 g/cm2, 43.33% and 19.57%, respectively.

There was a disparity in the interactive effects of land use type and depth on the mean weight diameter, soil temperature and soil penetration resistance. The highest values were recorded at a vegetable farm with depths of 0-20, residential area depths of 0-20 and residential areas with depths of 0-20 with values of 0.16 mm, 37.40°C and 40.00 N/cm, respectively, and the lowest values were obtained at residential areas with depths of 20-40, vegetable farms with depths of 20-40 and vegetable farms with depths of 20-40 with values of 0.07 mm, 25.37°C and 9.00 N/cm, respectively. There was a discrepancy in the interactive effects of land use type and depth on the soil moisture content; the highest value was recorded at a vegetable farm with a depth of 20-40 cm/cm3, with a value of 0.35 cm^3/cm^3, and the lowest value was obtained at an arable farm with a depth of 0-20 cm^3/cm^3.

Discussion

The greatest range of particle sizes was found in the flood plain as a result of soil deposited by erosion, and most of the soils in the arid region were recently formed soil and sandy. This is supported by Girma (2020). The soil textures of the different land use systems are sandy loam, sandy clay loam and loam. In all the land use systems, the sand fraction was dominant, ranging from 40% - 61%. In all land use systems, the sand fraction is dominant, ranging from 40% - 61% in arid regions (Geetha et al., 2021). A high bulk density was found in the residential area, and the 20-40 cm depth was affected by a low soil organic matter content, which promoted soil compaction. This is supported by Girma (2020), who reported that the high bulk density recorded under residential land, which increases with depth, might be a result of low organic matter content, increased soil disturbance, and compaction from the repeated movement of load, and the downwards increase in the soil bulk density might be explained by more compaction by less root penetration in the overlying soil and lower soil organic matter in the subsurface layer.

The highest range of total porosity was found at the vegetable farm, and the 0-20 cm depth was affected by the high organic manure content and minimum tillage. These findings are in line with those of Asmare et al. (2023), who reported high porosity in a vegetable farm as a result of an increase in soil organic matter. The highest water holding capacity was found on the flood plain, and the 0-20 cm depth was a result of the high clay and organic matter contents. This finding was in line with previous findings (Asmare et al., 2023). A higher MWD was observed at the vegetable farm, and the 20-40 cm depth was a result of the high organic manure content and minimum tillage. These findings are in line with those of Asmare et al. (2023). The higher soil temperature in the residential area at 20-40 cm was a result of a low soil organic matter content and compaction as supported by Girma (2020). However, the higher soil penetration resistance found in the residential area and at depths of 20-40 cm was a result of the low soil organic matter content and compaction.

Table 4. *Interaction effects of Land use types and Depth on Soil Physical Properties*

Land use types	Depth (cm)	Pb (g/cm^2)	%TP	%WHC	MWD(mm)	Temp(C^O)	P.R (N/A)	θv (cm^3/cm^3)
Arable Farm	0-20	1.43^{cd}	46.00^{de}	22.63^{cd}	0.09^{ef}	36.83^{a}	39.67^{a}	0.11^{g}
	20-40	1.49^{a}	43.33^{g}	21.17^{de}	0.07^{f}	34.20^{b}	19.00^{e}	0.20^{de}
Flood Plain	0-20	1.38^{f}	48.000^{b}	30.53^{a}	0.14^{abc}	34.60^{b}	38.33^{ab}	0.12^{fg}
	20-40	1.41^{de}	46.67^{cd}	28.87^{a}	0.12^{bcd}	33.37^{bc}	12.67^{h}	0.26^{c}
Mango Plantation	0-20	1.41^{de}	46.67^{cd}	21.73^{cde}	0.08^{ef}	31.63^{d}	36.67^{bc}	0.19^{de}
	20-40	1.50^{a}	43.33^{g}	20.73^{de}	0.07^{f}	28.90^{e}	14.00^{gh}	0.21^{d}
Neem Plantation	0-20	1.39^{ef}	47.667^{b}	25.53^{b}	0.1^{cde}	34.07^{b}	35.67^{c}	0.13^{f}
	20-40	1.44^{c}	45.67^{e}	22.57^{cd}	0.10^{def}	32.23^{cd}	16.33^{fg}	0.20^{de}
Residential Area	0-20	1.39^{ef}	47.33^{bc}	24.03^{bc}	0.08^{ef}	37.40^{a}	40.00^{a}	0.12^{fg}
	20-40	1.47^{b}	44.33^{f}	21.47^{cde}	0.07^{f}	34.63^{b}	18.33^{ef}	0.19^{e}
Vegetable Farm	0-20	1.36^{g}	49.00^{a}	25.60^{b}	0.16^{a}	28.10^{e}	32.67^{d}	0.31^{b}
	20-40	1.38^{f}	48.00^{b}	19.57^{e}	0.15^{ab}	25.37^{f}	9.00^{i}	0.35^{a}
LSD (0.05)		0.02	0.93	2.83	0.03	1.39	2.37	0.02
SE±		0.01	0.45	1.36	0.015	0.67	1.14	6.27E-03

Pb=Bulk Density, TP=Total Porosity, WHC=Water Holding Capacity, MDW= Mean Weight Diameter, PR=Penetration Resistant, θv=Volumetric Moisture Content, LSD=Lease Significant Difference and SE= Standard Error LUT= Land use types. The mean values followed by the same letters are not significantly different at 5% probability level.

This is supported by the findings of Jal et al. (2020) and Girma (2020), who reported that the highest penetration resistance recorded under residential land might be linked to low organic matter content, increased soil disturbance, and compaction from the repeated movement of load. Higher soil moisture content was found on the vegetable farm and at depths of 20-40 cm as a result of the high organic manure content and minimum tillage. This finding was in line with that of Asmare et al. (2023).

Conclusion

This study revealed inconsistency in soil properties among the different land use types. This study revealed that the study of land use types and their impacts will greatly help planning work and will reveal future planning methods. Thus, the understanding of land use types should be strongly intensified for ecosystem management and sustainability. This research showed that, compared with other land use types, plantations restore good soil physical and chemical properties. Based on these findings, Neem Plantations and Vegetable Farm had good soil physical properties at different soil depths. The following recommendations have been highlighted for sustainable land use in the study area.

a. Since the soil of the study areas under different land use types is well understood, proper management practices and land use management techniques, such as the planting of more trees and the proper use of animal dung, should be encouraged.
b. Vegetable farms and need plantations should be considered to improve the soil physical properties of the study area.

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Transfer Factors of Sr-90 from Corn Grown on Four Soils Typical of Bulgaria

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Abstract

Transfer factors of technogenic radionuclide strontium-90 were studied in vegetation experiment in four soils typical of Bulgaria. The four soil types were – Alluvial meadow (*Fluvisol*), Smolnitsa (*Pellic Vertisol*), Cinnamon forest soil (*Chromic Luvisol*) and Leached chernozem (*Haplic Chernozem*), respectively. The agricultural crop under study was corn.

It was found the content of strontium-90 was the highest in the leaves of the plant, less in the stems and the least in the generative organs of the crop – the grain. The data of the transfer factors obtained for the four soils typical of Bulgaria were comparable with the results cited by other authors for soils specific for temperate environments.

Higher uptake of strontium-90 was observed in corn grown on *Chromic Luvisol* and *Fluvisol* compared to *Pellic Vertisol* and *Haplic Chernozem*, most probably due to the lower content of physical clay, exchangeable calcium and magnesium and humus in the first two soil types.

Keywords: strontium-90, transfer factors, accumulation of radionuclides in plants

Introduction

The nuclear fission product strontium-90 is one of the most hazardous pollutants of the biosphere. One of the pathways the radionuclide enters the food chain is absorption from soil into plants. Therefore it is important to study to what extent different plant species accumulate Sr-90, or the so-called transfer factors of the radionuclide from soil to plant. This would allow to alter the diet of animals and humans at high levels of radioactive soil contamination.

Accumulation of radionuclides in plants depends on a number of factors as the properties of the radionuclide, soil properties as sorption and cation exchange capacity, presence of competing ions, plant properties as rhizosphere effects, etc. (Burger, Lichtscheidl, 2019; Ehlken, Kirchner, 2002). In this regard it was of interest to create a database of transfer factors for different agricultural products grown on soil types characteristic of Bulgaria.

The aim of the present study was to determine the uptake of Sr-90 in corn grown on four soils typical of the country so that, in the case of radioactive contamination of the soil, to utilize those parts of the plant which would least contribute to the additional dose load of people and animals.

Materials and Methods

The vegetation pot experiment was conducted with soils taken from the experimental fields of ISSAPP "N. Pushkarov" - Tsalapitsa (Plovdiv region), Gorni Lozen (Sofia region), Chelopechene (Sofia region), Gorni Dabnik (Pleven region). The four soil types were – Alluvial Meadow (*Fluvisol*), Smolnitsa (*Pellic Vertisol*), Cinnamon Forest soil (*Chromic Luvisols*) and Leached Chernozem (*Haplic Chernozem*), respectively.

The experiment was carried out in pots of 3.5 kg soil in three replicates and two controls. Nutrients were added to the soil in amounts guaranteeing the normal vegetation of the plants (calcium nitrate - 31 g/kg soil, monopotassium phosphate - 0.07 g/kg, potassium nitrate - 0.14 g/kg and magnesium sulfate - 0.07g /kg).

After 10 days necessary to reach natural humidity and equilibrium in the soil the radioactive isotope in the form of a soluble salt $Sr(NO_3)_2$ in the respective activity and a certain volume of distilled water were introduced in such a way as to simulate conditions of soil contamination by irrigation water during fallout in the event of sudden change in environmental radioactivity. After another 10 days required for the penetration of the radioactive solution into the entire volume of soil, corn (*Zea mays* ssp. *mays*) was sown.

In the end of the vegetation period the plants were harvested and dried at 110°C to air dry weight.

The specific activity of strontium-90 was determined by measuring the activity of the daughter product yttrium-90 according to validated interlaboratory method (Naydenov, et al., 2010). The samples were incinerated at 550°C. Yttrium and strontium carrier were added to the ash samples and they were boiled with 65% nitric acid for 10 min and filtered. Yttrium was extracted from the filtrate three times with tributyl phosphate presaturated with 65% nitric acid. The organic phase was re-extracted with distilled water. Yttrium was precipitated as oxalate from the aqueous extract, filtered and fixed on a plate. The plate was measured for 1 hour in a low background alpha-beta gas flow counter MPC 9300 - manufactured by PIC USA. Calibration was carried out with a standard solution of strontium-90.

To estimate Sr-90 accumulation in plants, the corresponding transfer factors (Tf) – the ratio of the activity in 1 gram of air-dry plant mass to the activity in 1 gram of air-dry soil, were determined (IAEA, 2010).

Threefold repetition of the procedure of Sr-90 determination in the plants from the respective soil was carried out. Standard deviation from the mean was determined. The confidence interval is two-sigma (95%).

Results and Discussion

To study the influence of soil characteristics on the radionuclide plant uptake analyses of soil texture, agrochemical and chemical properties of the soils were carried out according to generally accepted methods, validated in ISSAPP "N. Pushkarov". The results are presented in Tables 1, 2 and 3.

Table 1. *Soil texture in % to air dry state*

№	Soil type	Hygro-scopic moisture, %	Sum >1	1-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001	Sum <0.01
1	*Fluvisol*	1.08	0.0	47.0	20.4	8.1	11.3	8.9	4.3	24.5
2	*Pellic Vertisol*	4.06	0.0	18.5	16.9	9.0	10.2	11.0	34.4	55.6
3	*Chromic Luvisol*	2.43	0.0	24.6	20.2	7.1	12.5	10.4	25.2	48.1
4	*Haplic Chernozem*	3.54	0.0	5.1	27.5	12.4	16.2	10.7	28.1	55.0

Table 2. *Agrochemical characteristics of studied soils*

№	Soil type	pH	Σ N $NH_4 + NO_3$	P_2O_5	K_2O	Humus
		H_2O	mg/kg	mg/100g		%
1	*Fluvisol*	5.9	23.0	15.1	19.1	1.00
2	*Pellic Vertisol*	6.1	12.0	4.4	25.6	2.30
3	*Chromic Luvisol*	6.8	33.4	12.6	26.2	1.05
4	*HaplicChernozem*	7.8	44.9	16.1	39.0	2.24

Table 3. *Cation exchange capacity ($T_{8.2}$), strongly acidic (T_{SA}), weakly acidic (T_A) positions of the soil adsorbent, total acidity ($H_{8.2}$) and composition of the most important exchangeable adsorbed cations*

№	Soil type	$T_{8,2}$	T_{SA}	T_A	$H_{8,2}$	Al_{exch}	Ca_{exch}	Mg_{exch}	Base saturation %
		mequ/100g							
1	*Fluvisol*	13.6	-	-	0.0	0.0	11.6	2.0	100.00
2	*Pellic Vertisol*	30.9	27.2	3.6	3.0	0.0	24.8	3.1	90.29
3	*Chromic Luvisol*	21.8	18.7	3.1	2.7	0.0	16.6	2.5	87.61
4	*Haplic Chernozem*	31.3	-	-	0.0	0.0	26.8	4.5	100.00

The obtained results show the soil types under study *Pellic Vertisol* and *Haplic chernozems* are characterized by a heavy sandy clay composition - the content of physical clay is over 50%, of silt - about 30%. This predetermines the high sorption capacity – over 30 Mequ/100g. The soil absorption complex has a high saturation of basic cations - over 90%, of which the exchangeable calcium is between 25 and 27 Mequ/100g. The amount of humus in the two soil types is average – 2 ÷ 3 %.

Chromic Luvisol from the Chelopechene area has a sandy-clay soil texture too, but the degree of saturation with bases and exchangeable calcium in particular, is lower compared to that of the soil types described above. The humus content is low -1.05 %.

Fluvisol is characterized by the lowest sorption capacity, due to the slightly sandy-clay soil texture and the relatively low content of physical clay - 24.5% and silt - 4.3%. The degree of saturation with bases is very high (100%). The humus content is low -1%.

The results of the radiochemical determination of strontium-90 in the different parts of the corn samples are presented in Table 4. The values are averaged from the results of three repetitions of the radiochemical procedure for each part of the plant from the respective soil type. The calculated standard deviation is given in brackets. Fig. 1 shows the percentage distribution of Sr-90 in different parts of the plant. Grain was not obtained on *Chromic Luvisol* and *Haplic Chernozem*.

Table 4. *Activities of strontium-90 in the soil and the organs of corn – Bq/g*

№	**Soil type**	**Sr-90 in soil**	**Sr-90 in leaves**	**Sr-90 in stems**	**Sr-90 in grain**
1	*Fluvisol*	0.47	0.72±0.22 (30%)	0.51±0.06 (12%)	0.03 ±0.006 (21%)
2	*Pellic Vertisol*	0.51	0.36±0.09 (24%)	0.32±0.06 (18%)	0.02±0.005 (20%)
3	*Chromic Luvisol*	0.51	1.03±0.32 (31%)	0.66±0.09 (14%)	-
4	*Haplic Chernozem*	0.52	0.65±0.13 (20%)	0.50±0.04 (9%)	-

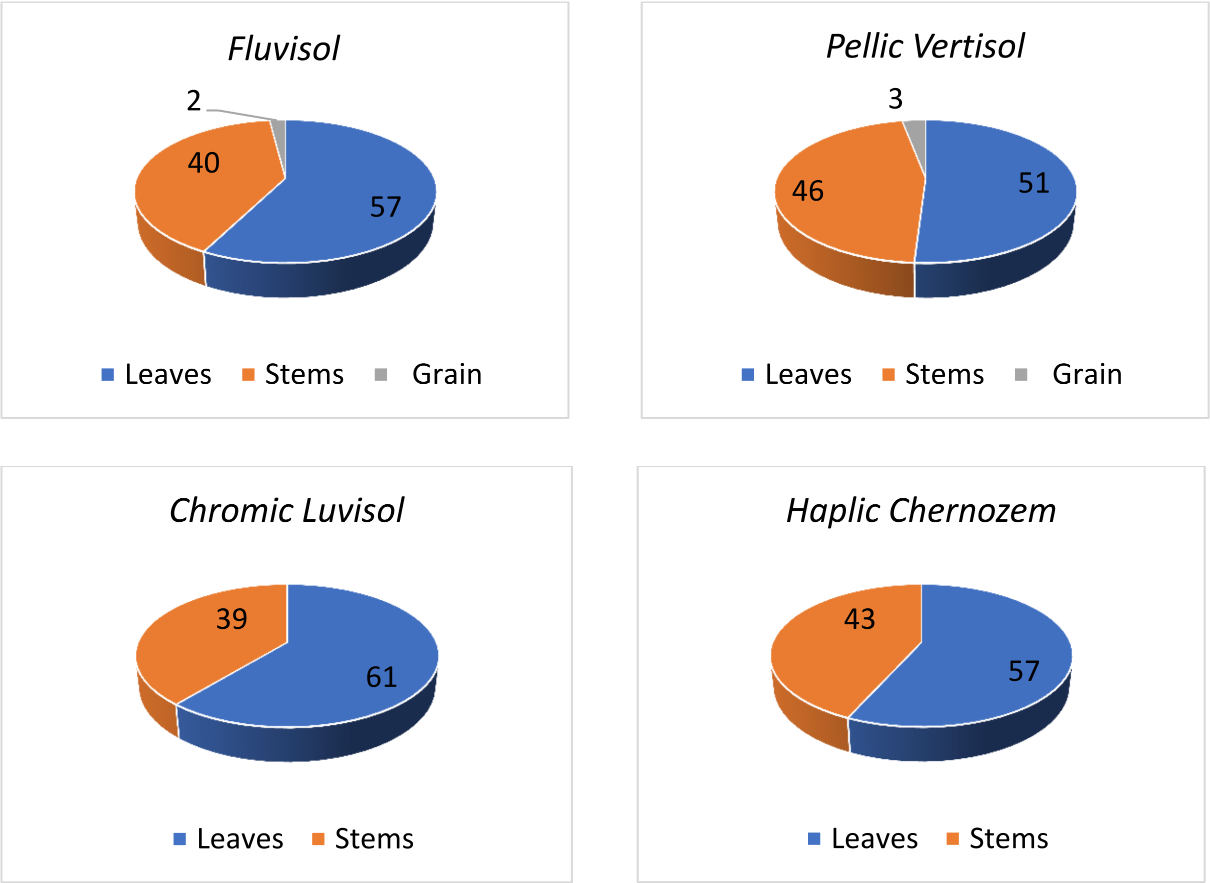

Fig. 1. *Percentage distribution of Sr-90 in different parts of the plant.*

It can be seen from the results the content of strontium-90 is the highest in the leaves of the corn, less in the stems and the least in the grain. As noted by other authors, radionuclides usually accumulate in the leaves and stems and to less extent in the generative organs of the plant (Evans, Dekker, 1962; IAEA, 2009)

The transfer factors (Tf) were determined – the ratio of the specific activity of the radionuclide in 1 gram of air-dry plant and the specific activity in 1 gram of air-dry soil, to evaluate the degree of accumulation of the radionuclide from the respective soil type in the plant. The results are presented in Fig. 2.

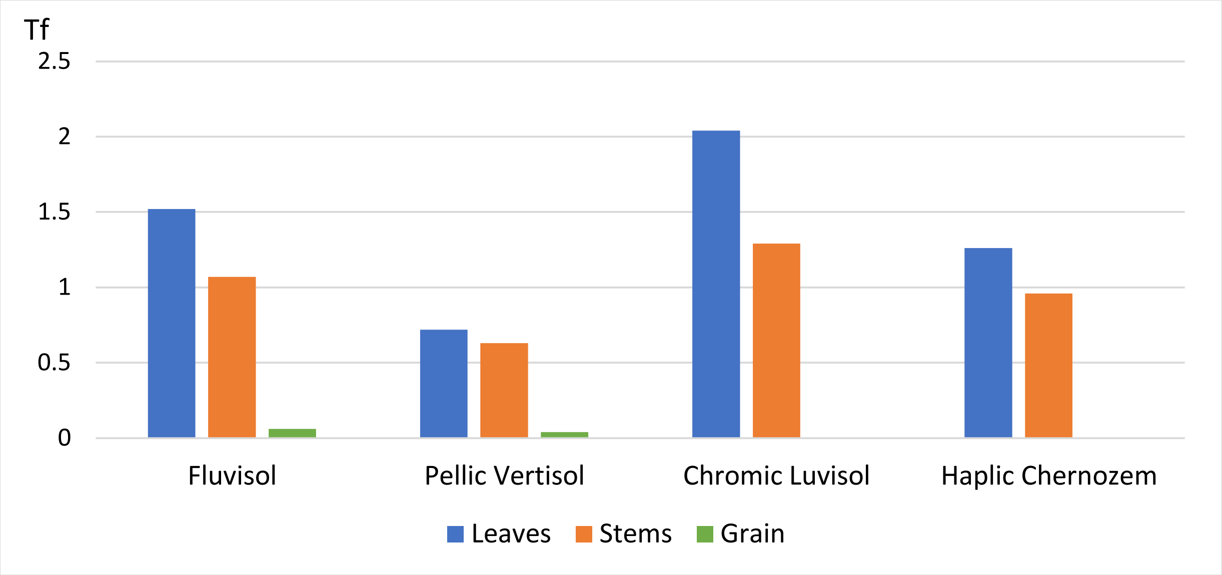

Fig. 2. *Transfer factors of Sr-90 in corn leaves, stems and grain of the soil types under study*

For comparison, transfer factors for Sr-90 in corn derived from summarized data on soil experiments carried out in temperate environments are as follows (IAEA, 2010):

- Grain: sand – 0.04÷2.6 (average 0.52); loam – 0.15÷ 0.86 (average 0.36); clay - 0.002÷0.39 (average 0.069)

- Leaves and stems: sand – 0.12÷3.0 (average 0.82); loam - 0.28÷1.4 (average 0.7); clay – 0.18÷1.1 (average 0.7)

It can be seen the obtained results for the four soils typical of Bulgaria are comparable with the data cited by other authors.

The main factors that influence the migration of radionuclides in soil and their accumulation in plants can be divided into three groups: characteristics of the soil, properties of the radionuclide and physiology of the plant itself.

Sr-90 accumulation in plants is highly influenced by soil texture. The results show the corn uptake of Sr-90 from soil types *Pellic Vertisol* and *Haplic Chernozem*, characterized by a physical clay content of more than 50%, is lower compared to the other two soil types due to the fixation of the radionuclide to the clay particles of the soil complex (Valcke, et al., 1997; Sysoeva, et al., 2005).

From physicochemical characteristics of the soils the content of exchangeable calcium and exchangeable magnesium was found to reduce Sr-90 uptake by plants. In *Pellic Vertisol* and *Haplic Chernozem*, the amount of exchangeable calcium is between 25 and 27 Mequ/100g, and the amount of exchangeable magnesium is 3.1 and 4.5 Mequ/100g compared to Ca_{exch} – 11.6 and 16.6 and Mg_{exch} – 2.0 and 2.5 in Fluvisol and Chromic Luvisol, respectively. The content Ca_{exch} and Mg_{exch} leads to reduction of radionuclide bioavailability to plants due to the competition of ions for positions in the soil absorption complex. The higher content of exchangeable calcium and magnesium in soils may block to a great extent the accumulation of the radionuclide by the plant.

Liming of soils is one of the measures for reduction of radiostrontium plant uptake. It increases soil pH and leads to preferential absorption of calcium by plants. (Veresoglu et al., 1996; Tyler and Olson, 2001).

Higher Sr-90 transfer factors were observed in *Fluvisols* and *Chromic Luvisols*, characterized by lower content of the clay component and lower amount of exchangeable calcium and magnesium.

From the agrochemical characteristic of the soils a major factor that was found to be crucial for plant uptake of strontium-90 was the content of humus. Soluble Sr-90 is adsorbed in humus and leads to the formation of colloidal organic compounds such as humic and fulvic acids. Association with fulvic acids leads to the formation of soluble colloids that mobilize the radionuclide in low pH soils, while association with humic acids leads to the formation of stable complexes and reduced transfer of Sr-90 to plants (Burger and Lichtscheidl, 2019).

The correlation between content of humus in the four soil types under study and transfer of Sr-90 to corn plants is presented in Fig. 3. It shows the reduction of radionuclide plant uptake in soils *Pellic Vertisol* and *Haplic Chernozem* charecterised by higher humus content.

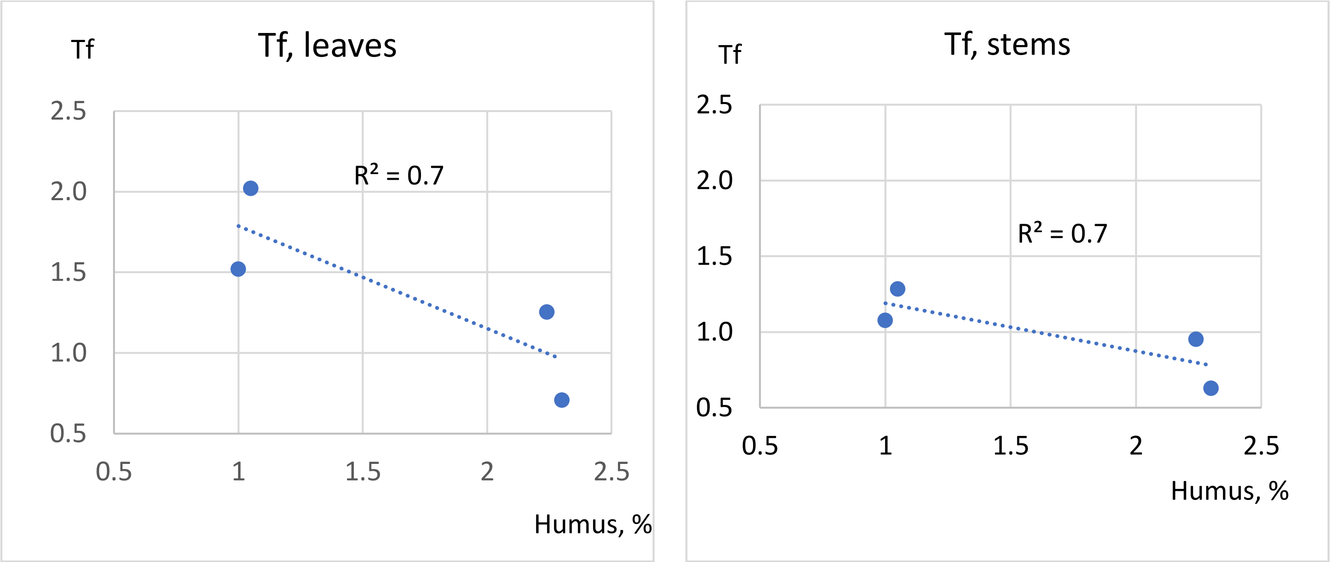

Fig. 3. *Correlation between content of humus in soils and Tf of Sr-90 in corn plants*

Conclusions

The results of the experiment carried out show the absorption of strontium-90 is the highest in the leaves of corn, less in the stems and the least in the generative organs of the plant - the grain. The transfer factors obtained are comparable to those cited by other authors for corn plants grown on soils from the temperate climate zone. Higher uptake of strontium-90 was observed in corn grown on *Chromic Luvisol* and *Fluvisol* compared to *Pellic Vertisol* and *Haplic Chernozem*. The major factors that were found to influence the higher uptake of Sr-90 by plants in the first two soils were the soil texture and the lower content of physical clay in particular, from the physicochemical characteristics of the soils - the lower amount of exchangeable calcium and magnesium and from agrochemical characteristics the lower content of humus.

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Study of Selected Rice (Oryza sativa) Producing Soil Characteristics of Wukari, North-Eastern Nigeria

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Abstract

The study examining the soil's characteristics for sustainable rice (Oryza sativa) production. The soils featured a sandy clay loam, loamy sand, and sandy loam texture. They were also deep and well-drained. Their pH values ranged from 5.00 to 5.70, indicating that they were generally somewhat acidic in response. The majority of the crops in the study area can be produced sustainably within this pH range. The pH of the soil often controls the availability and unavailability of the majority of nutrient components in agricultural productivity. It also controls how these nutrients are absorbed for a steady crop supply. Additionally, the soils' nutritional (OC, OM, TN & P) concentration was poor. While exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) were limiting variables in the research area, the percentage base saturation was high. A moderately suitable (S2) unit I and marginally suitable (S3) units II rating for rice cultivation was found in the suitability assessment of a few chosen Wukari soils. For increased rice yield in the area under study, significant soil amendment or management techniques specifically, the use of organic or inorganic fertilizer and planting timing have been suggested.

Keywords: soil characteristics, profile, morphology, rice-production

Introduction

Rice has been one of the main staples and important source of carbohydrates in the diet of Nigerians across all socioeconomic strata. The increased demand for rice leads to its importation. Because small-scale farmers cultivate the crop there, according to FAO (2014), Nigeria is one of the top importers of rice worldwide. The inability to meet the increasing demand for rice worldwide has been caused by several factors, including smallholder land holding, reliance on rain-fed agriculture, low irrigation development, poor planting material, low fertilizer application, inadequate storage facilities, and a weak agricultural extension system, even though global rice production has increased over the past 20 years (FAO, 2014).

This could be partially explained by the recent crop failures that have persisted, which have been caused by a lack of knowledge about the characteristics of the soil. This knowledge is crucial for the sustainable and intelligent usage of the soil. Inadequate agricultural productivity, which results from mismatching land properties with crop requirements, can also cause food loss and hence, affect economic growth. A deep awareness of the soil's characteristics will make managing it and determining whether a given crop is a good fit much easier. This soil information can be obtained by evaluating the land's suitability. Evaluating land involves estimating its potential for different applications (FAO, 1914). A land appraisal has been helping farmers to understand the limitations and potential of their land for specific uses. Evaluation, therefore, requires establishing the required crop requirements and modifying them for the terrain and soil conditions (Dent and Young, 1981). The identified limiting variables could be adjusted to better suit the needs of various crops and boost agricultural productivity. The aim of this study is to determine which soils of Wukari Local Government Area are appropriate for rice production.

Materials and Methods

The Study Area

The study was conducted in northern Jootar (coordinate: N07045.385’ E0090 45.953’), which is in Northeastern Nigeria and falls under Taraba State’s Wukari Local Government Area. The region has an average temperature of 29.38ºC and 135.2 mm of precipitation annually. Within the Southern Guinea Savannah Zone is the Wukari Local Government Area. Tiv, Jukun, Hausa, Ibo, and Idoma are among the people who have settled in the area; they are primarily traders. Basement and sedimentary rocks, which differ in character throughout the local government, underlie the region's geology. Afia, Jootar, and nearby local government areas including Takum, Logo, and Katsina Ala are home to the majority of the basement complex rocks, which are composed of old igneous and metamorphic rocks.

Field Work

In the field, auger point investigations were conducted at 100-meter intervals using the grid method of soil survey. Based on physiographic and vegetation changes, two soil units were distinguished. Each unit had a profile pit sunk in it, for a total of two pits. Soil samples were taken from the profile pits and documented using the criteria for describing soil profiles (Soil Survey Staff, 2017). The gathered soil samples were meticulously labeled for examination in a lab.

Sample Preparation and Laboratory Analysis

The grid method of soil surveying was used in the study area. Auger point investigations were performed at 100-meter intervals along traverses that were cut on the baseline. Two soil units were identified as a result of these investigations, and one profile pit was sunk for each unit, for a total of two profile pits. The pits were described using the instructions for defining soil profiles that the soil survey crew (2014) gave. Samples were gathered, properly labeled, and transported to a lab for chemical and physical analysis. Standard laboratory procedures were used to analyze the physical and chemical characteristics of the soil samples collected from the field. The bulk soil samples collected from the field were left to air dry for a week. The soil samples were crushed gently and then sieved through a 2 mm sieve for laboratory analysis.

Particle size distribution was determined using the Buoyoucos hydrometer method by Day (1965) with sodium hexameta-phosphate as the dispersing agent; soil pH was measured using a pH meter in water using a 1:1 soil/water ratio; total soil nitrogen was determined using the Kjeldahl method (Bremner and Mulvancy, 1982); extractable P was determined using the Bray-1 method (Murphy and Riley, 1962); base saturation was calculated by dividing TEB by ECEC and multiplying the result by 100%; and CEC was measured using the procedures described in IITA (2015).

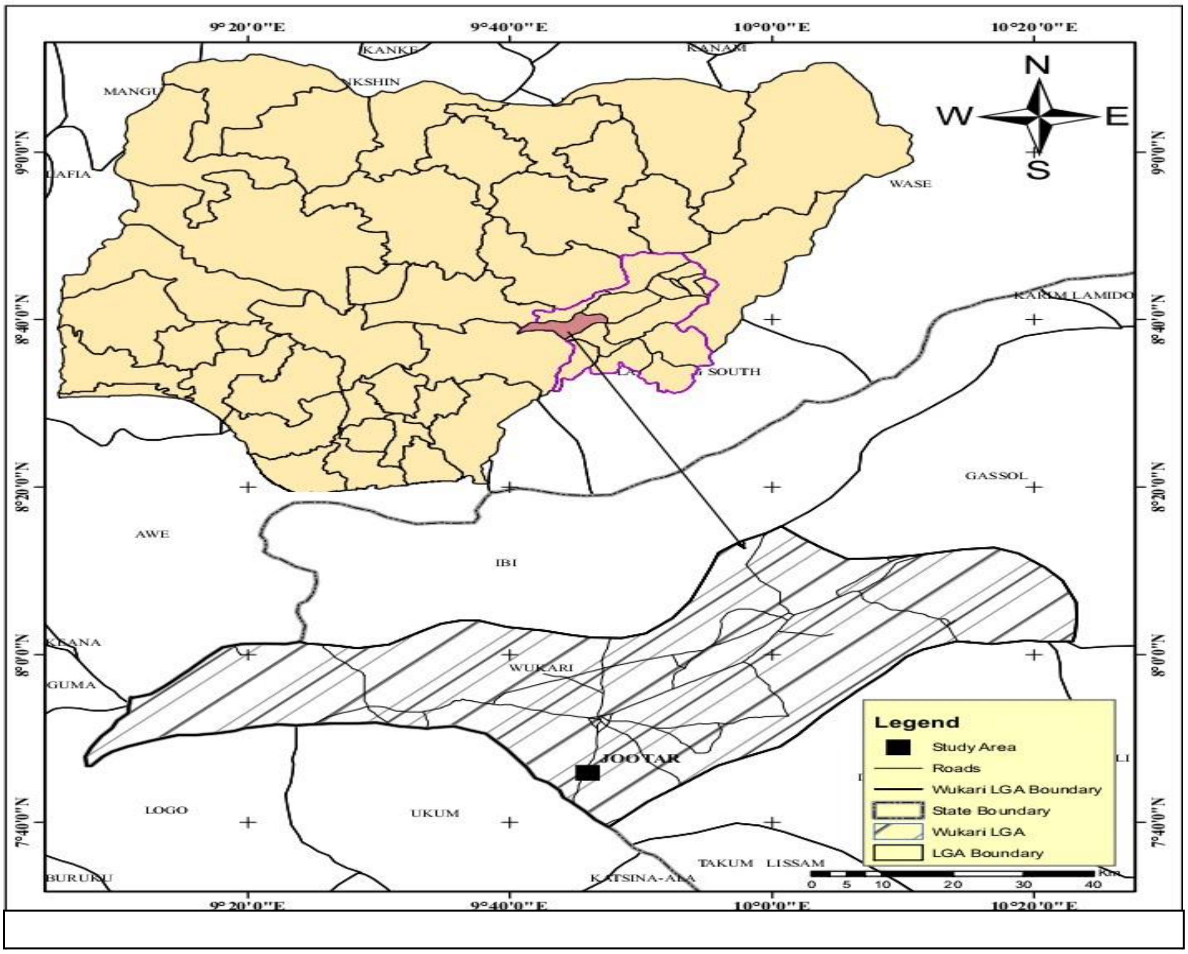

Figure 1. *Map of Wukari LGA showing Location of study area, (source: GIScore, (2023))*

Result and Discussion

Morphological properties of the soils

Table 1 provides information about the morphological features of the study area. In general, the soils had a slope gradient of roughly 0-2% and were relatively deep (120 cm) and almost flat. The soils had good drainage. The research area's common soil structures included: • Moderate and strong medium subangular blocky, which were present in the subsurface horizons of all the soil profiles examined; • Weak and moderate medium granular and weak fine granular, which characterized the profiles' surface horizons (Table 1).

Soil genesis and agricultural productivity depend on the natural aggregation of soil particles. The pace at which water and nutrients move from the surface soil to the roots at the subsurface soil, as well as numerous other processes including infiltration, percolation, excess water drainage, aeration, and water holding capacity, are all significantly impacted by a soil's structure. Therefore, thorough study is necessary to manage plants properly, which promotes plant growth and productivity. The composition of the soil structure in that area can be explained by the relatively high clay content and moderate amount of organic matter in the studied area, which promote soil particle aggregation in the A horizon. A well-aggregated soil has a good crumb structure (Idoga, 1985; Ufot, 2012). Because it results in structural weakness, plant nutrients are usually limited in soils with low organic matter content (Akinyemi and Vivian, 2001).

Table 1. *Morphological properties of the study Area*

Horizon	**Depth**	**Color (moist)**	**Mottle**	**Texture**	**Structure**	**Consistency**	**Root**	**Drainage**	**Boundary**
Pedon 1 Profile 1: (Coordinate = N07^{0}57’185’, E09^{0}45’990 elevation = 595)									
Ap	0 -25	5YR6/8 (reddish yellow)	Nil	SCL	1MGR	Friable	CF – FM	Well Drained	CS
AB	25 – 55	10YR6/4 (Pale red Yellow)	Nil	SCL	1MGR	Friable	MFV, MF, MM	Well Drained	CW
Bt$_1$	55 – 80	7.5YR4/5 (Strong Brown)	Nil	LS	2MSBK	Firm	CF, FM	Well Drained	CS
Bt$_2$	80 -100	2YR6/8 (Light red)	Nil	SL	3MSBK	Very Firm	FF, FC	Well Drained	CW
Bt$_3$	100 -120	5YR4/4 reddish brown	Present	LS	1MSBK	Firm	Vff	Well Drained	CS
Pedon 1 Profile 2: (Coordinate = N07^{0}57’ 212’, E09^{0}45.984 elevation = 597m)									
Ap	0 -25	7.5YR5/8 (strong Brown)	Nil	LS	1FGR	Firm	Cf, fm	Well Drained	CS
AB	25 – 55	5YR6/8 (light reddish Brown)	Nil	LS	2MGR	Friable	Vff, vfm	Well Drained	CW
BA	55 – 80	2.5YR 6/4 Reddish brown	Nil	LS	3MSBK	Very Firm	Cf, cm	Well Drained	CW
B$_1$	80 -100	5YR 6/4 Light reddish brown	Nil	LS	1MGR	Friable	Ff	Well Drained	CW
B$_2$	100 -120	10YR6/4 pale red	Nil	LS	2MSBK	Friable	Mff, mfm	Well Drained	CW

Ls=Loamy Sand, SL = Sandy Loam, SBK = Sub Angular Blocky, LC = Loamy Clay, S = Sand, C = Common M = Many, F = Few, VF = Very Few, 1 = Fine, 2=Medium, 3=Coarse, R=Roots, CS=Clear and smooth, St = Structure, SCL Sandy Clay Loam, SBA = Sub-angular, GL = Granular, CB = Crumby

The surface horizons of the research area's soils exhibit a range of colors. Complete decomposition of organic matter (oxygen rich soil) was indicated by the soils' reddish yellow (5YR 6/4 moist), reddish brown (2.5YR 6/4 moist), and strong brown (7.5YR4/5 and 7.5YR5/8) colors. The light reddish-brown color (5YR 6/4 and 2.5YR 6/4 moist) on the surface horizon may be related to the humified nature of the soil organic matter, but the pale red yellow (10R6/4 moist) color may be caused by the presence of unhydrated iron oxide, most likely hematite.

Physical Properties of the soils

The flow of solutes, water, heat, and air through soil is made possible by its physical properties. They include the soil's color, texture, and structure. The behavior and applications of the soil depend on these properties. The soils of the study area were primarily sandy loam in both profiles, with profile 1's surface strata showing sandy clay loam. Both profiles had sandy loam subsurface horizons. These might be ascribed to the study area's parent materials (Table 2). The percentage of sand fractions in the particle size distribution (PSD) rose with depth in profile 1 and was dispersed unevenly in profile 2 (Table 2). All of the profiles had an uneven distribution of silt and clay concentrations with depth. The minor topographic variances may be the cause of the relative PSD disparities between the units.

The most prevalent particle size fraction in both surface and subsurface horizons across all profiles was the % sand fraction. The nature of the parent materials, the ongoing weathering of the rocks, and the downward flow of the clay through the soil mass are the main causes of the high sand component found in most savannah soils. Due to their high sand content, the soil is extremely susceptible to erosion since raindrops and flowing water can quickly separate them. The lower subsurface soils' colluvial or saprolitic origin may also be the cause of the high sand content in some subsurface strata (Yau et al., 2015). Since sand makes up a significant amount of the soil, it readily separates when rain or flowing water strikes it, leaving the land particularly vulnerable to erosion. Similar findings were found by Yakubu (2006) in the soils of Sokoto State.

Table 2. *Physical properties of the soils*

Horizon	Depth (cm)	Silt %	Clay %	Sand %	SCR	TC	BD (gcm-3)	PO%	Moisture Contents %
Pedon 1. Profile 1: coordinate N07^{0}45.385’ E09^0 45.953’ Elevation 507									
Ap	0 -25	20.40	20.00	59.60	1.02	SCL	2.01	24.00	31.55
AB	25 – 55	10.40	22.00	67.60	0.47	SCL	2.17	18.00	15.35
Bt$_1$	55 – 80	20.40	4.00	75.60	5.10	SCL	2.12	20.00	15.27
Bt$_2$	80 -100	14.40	2.00	83.60	7.20	LS	2.15	19.00	15.75
Bt$_3$	100 -120	14.40	4.00	63.60	3.60	LS	1.57	34.00	50.07
Pedon 2 profile 2 coordinate N07^{0}45.600’ E09^0 45.064’ Elevation 495									
Ap	0 -25	14.40	4.00	81.60	3.60	LS	1.54	42.00	50.00
AB	25 – 55	12.40	4.00	83.60	3.10	LS	1.99	25.00	9.26
BA	55 – 80	12.40	2.00	85.60	6.20	LS	2.06	22.00	19.44
B$_1$	80 -100	12.40	4.00	83.60	3.10	LS	2.08	22.00	15.84
B$_2$	100 -120	18.40	2.00	79.60	9.20	LS	1.45	45.00	57.54

SCR = Silt clay ratio, TC = Textural Class, BD = Bulk density, PO = Porosity, SCL = Sandy clay Loam, SL = Sandy Loam

Pedon 1

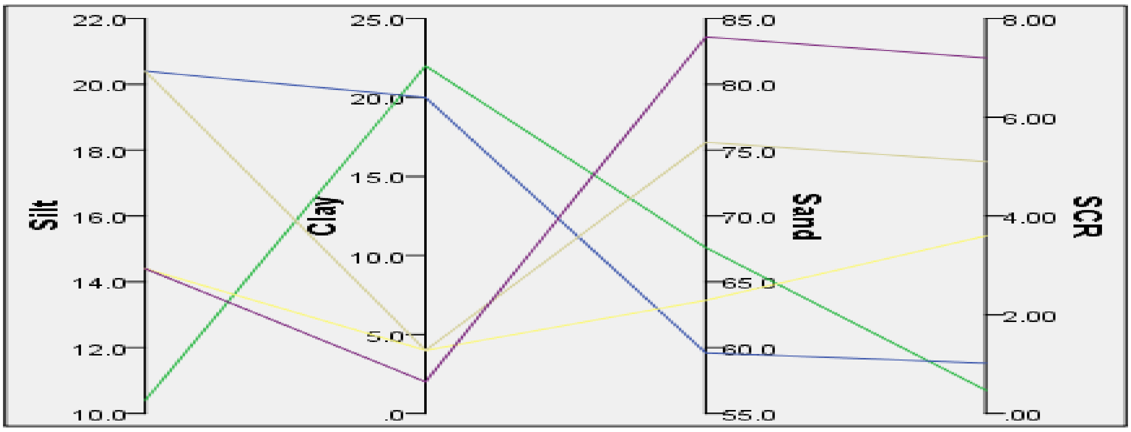

Figure 2. *Relationship between Sand, Silt and Clay*

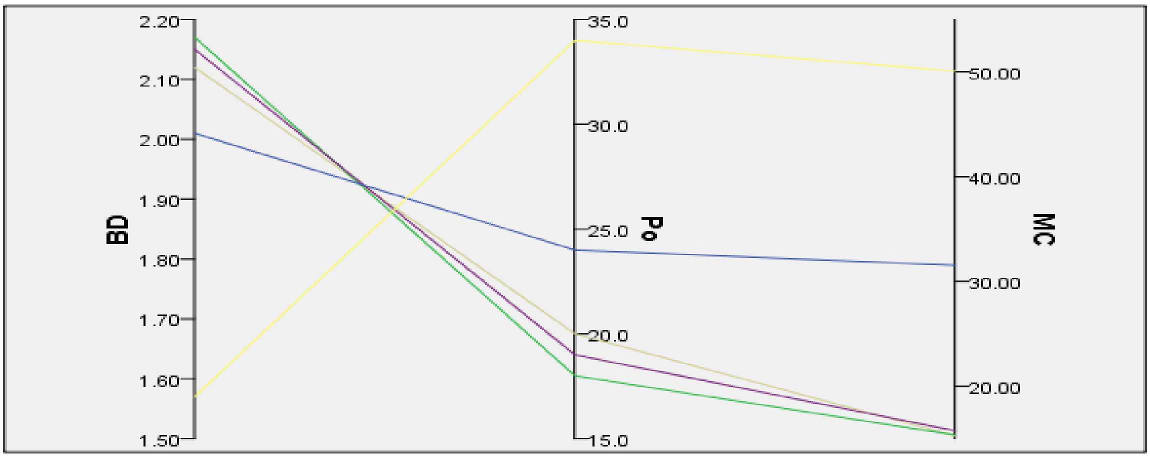

Figure 3. *Relationship between bulk density, porosity and moisture content*

Pedon 2

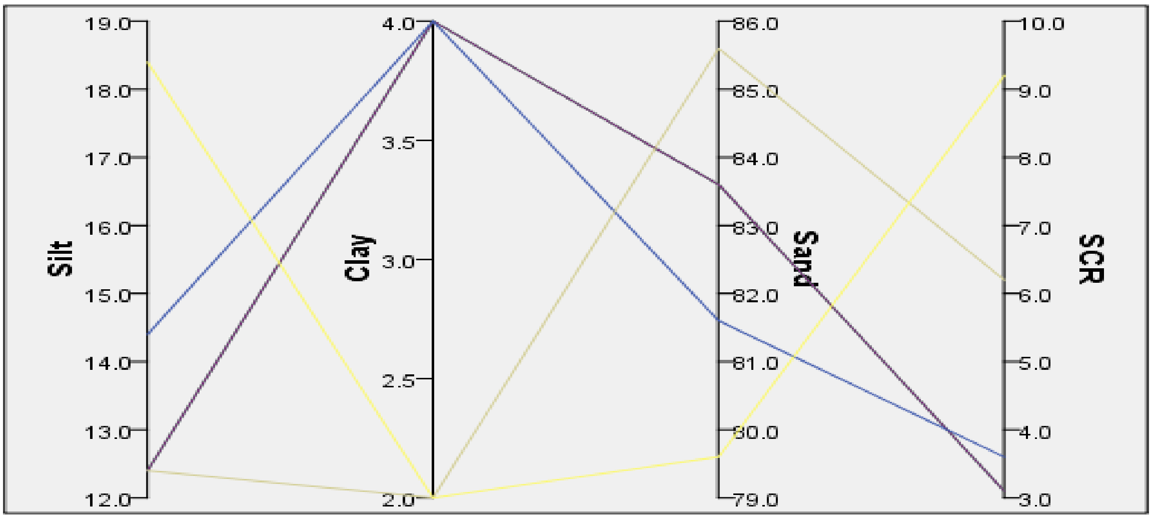

Figure 4. *Relationship between Sand, Silt Clay and Silt/Clay*

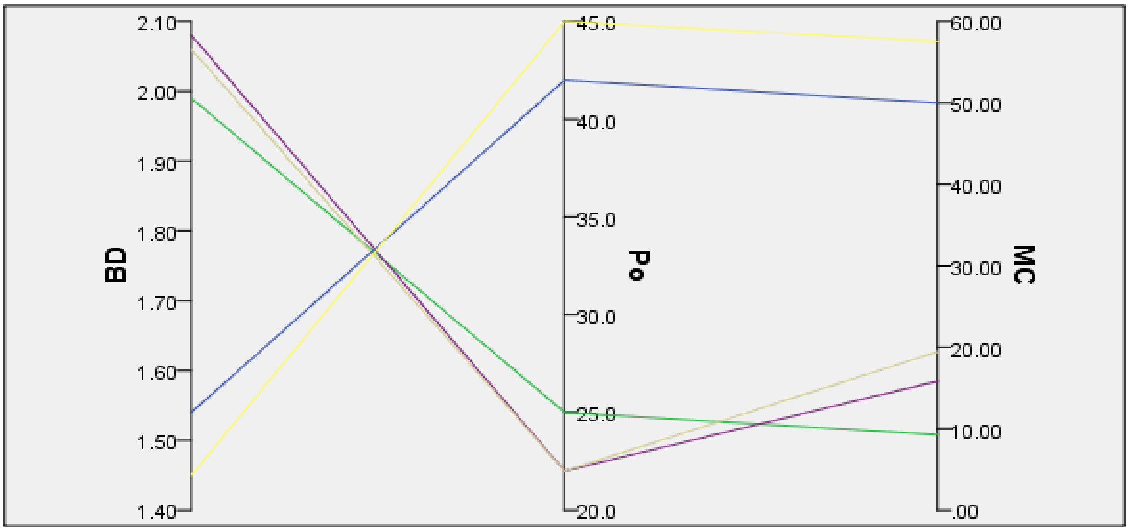

Figure 5. *Relationship between Bulk density, Porosity and Moisture content*

Chemical properties of the soils

Table 3 displays the soils' chemical characteristics. According to the findings, the study area's soils had a somewhat acidic reaction. In H20, the pH values ranged from 5.00 to 5.70. In profile 1, the pH values rose with depth, whereas in profile 2, they fell. The moderate soil reaction may be caused by the direct deposition of crop and vegetable residues on the soil surface, followed by their breakdown to release basic cations into the soil (Usman et al., 2019). Usman et al. (2019) and Ugwu et al. (2001) suggest that profile 1's higher pH at the surface than beneath could be due to nutrient biocycling and high percentage base saturation at the surface horizon. According to Idoga and Ogbu (2012), leaching of bases and frequent crop harvesting are to blame for the decrease in soil pH with depth observed in Pedon 1. The breakdown of plant matter can also produce a variety of organic acids that lower the pH of the soil. Esu (2005) has highlighted that one of the main causes of the pH values declining with depth is the return of bases to the surface due to the pumping effect of the vegetation/crops.

The range of the organic carbon content was 0.99% to 0.3%. In every profile, the proportion of organic carbon content lacked a clear distribution pattern with depth (Table 3). In contrast to Agboola and Ayodele's (1985) assessments, which state that <0.4 = very low, 0.5-1.0 = low, 1.2-1.4 = moderate, 1.5-2.5 = high, and >2.5 = very high, the soils' organic carbon content was evaluated as low. The low organic carbon content may be caused by a number of causes, including grazing, bush burning (Kang, 1993), a long cropping season, a high rate of erosive degradation, harvested crop wastes that are not replaced, and poor management techniques (Landon, 1991). Total nitrogen levels were classified as low and varied from 0.34 to 0.67%. In both profiles, the distribution pattern of the total N values was irregular. There was a favorable correlation between the amount and distribution of organic carbon and total nitrogen. The reason for this is that the two naturally occur in comparatively constant ratios (Ayolagha and Opene, 2012). Moreover, denitrification and volatilization, which cause N loss, may also be to blame for the area's low N levels. Generally speaking, the low amount of nitrogen in the soil can be attributed to a variety of factors, including leaching, gaseous loss, release from plant tissues, surface runoffs, vegetation, human activity, and original soil pH.

According to Christensen (2001), the accessible phosphorus (P) content was classified low since it ranged from 2.97 to 9.35 mg/kg. He stated that < 3 mgkg-I = very low, 3-7 mgkg-1 = low, 7-20 mgkg-1 = moderate, and >20 mgkg-1 = extremely high. However, the low findings support Brady and Ray's (2014) assertion that most native soil has a low total P content, with the majority of that P existing in forms that are not very useful to plants. The floodplain's low level of organic carbon may potentially be the cause of the low available P. Similar to total N and organic carbon, the available P varied with soil depth, demonstrating the interdependence of the three. The low organic C to P ratio in the surface strata suggests that the majority of the P present was in organic form. Although wood ash can provide P, 50–80% of P in savannah soils comes from organic carbon (Ogieva, 2018).

Ca>Na>K>Mg was the descending order of the exchangeable bases. In every profile, the other total exchangeable bases—aside from magnesium—lacked a clear pattern of distribution with depth. There was a range of 4.23 to 5.25 cmolkg-1 of exchangeable Ca. While the sodium concentration ranged from 0.72 to 0.81 cmolkg-1, the potassium value varied from 0.07 to 1.90 cmolkg-1. All of the soil units had low levels of exchangeable bases (Mg, K, and Na) save from Ca. The low exchangeable bases of these soils may be caused by a variety of factors, including the type of parent materials beneath them, the extent of weathering, leaching, low activity clay, the very low amount of organic matter, erosion and surface runoff, and the lateral translocation of bases. Furthermore, the soil's capacity to draw in and retain cations in exchangeable forms was diminished by the low levels of organic matter and clay (Krasilinikoff et al., 2002). These findings supported Sanchez's (1976) theory that the soils of tropical savannah rapidly deteriorate due to continuous cropping. In the exchange complex, calcium was the most prevalent cation, with values ranging from 4.23 to 5.25 cmolkg-1. The predominance of calcium over other cations in these soils may also be due to the presence of calcium at exchange sites in soil that has a specific affinity for calcium, the fact that calcium is less readily lost from exchange sites, or the fact that it has a higher displacement ability than other cations in cation exchange reactions.

The range of the CEC values was 5.49 to 6.56 cmolkg-1. When compared to Esu's (1991) grade of <6 = low, 6-12 = moderate, and >12 = high, the CEC distributions were generally scored low to moderate and varied with depth in all profiles. Keep in mind that one of the best practical soil tests for estimating plant nutrient requirements is the soil's ability to retain cations. The amount of each cation element that will react with or displace it from the soil exchange sites determines its unique equivalent weight (Ufot, 2012; Brady and Ray, 2014). The low CEC values, however, suggested that the soils' capacity to hold onto plant nutrients was limited, necessitating proper soil management. The silicate clay minerals (Kaolinite), which are thought to be the predominant clay type in depressed soils, may be the cause of the soils' low CEC (Hassan et al., 2011). Adding organic carbon is one of the finest ways to increase the CEC of the soil. By enhancing the soil's ability to retain cations, these methods will increase the soil's capacity to retain nutrients for crop growth and optimal output. In comparison to the classifications suggested by FMANR (1990), which are as follows: <20% = very low, 20-40%, low = 40-60%, moderate = 60-80% = high, and >80% = very high, the percentage base saturation values of the soil (61.04 to 86.49%) were evaluated as moderately to very high. In every profile, the base saturation (BS) distributions did not match depth. The impact of harmattan dust, which is known to contain a high proportion of cations, especially Ca, and the active breakdown of plant litter, which releases cations into the soil surface, could be the cause of this (Idoga, 2002). The high B.S. (61.04 to 86.49%) is probably caused by the alluvial nature of the weathered minerals in the soil profiles, which release nutrients into the soil, as well as their insufficient leaching caused by many dry months and seasonal high-water tables.

Table 3. *Chemical Properties of the study area*

Horizon	Depth (cm)	pH (H2O)	OC	OM	TN	AVP	Ca	Mg	K	Na	TEA	CEC	BS
			←		(Mg/kg)	→	←	(%)	→			(Cmol/kg)	(%)
Pedon 1. Profile 1: coordinate N07^{0}45.385’ E09^0 45.953’ Elevation 507													
Ap	0 -25	5.25	0.21	0.36	0.53	5.94	4.26	0.0001	0.07	0.81	0.50	6.51	82.88
AB	25 – 55	5.15	0.03	0.05	0.67	9.35	4.33	0.0001	0.10	0.78	0.20	5.49	83.11
Bt$_1$	55 – 80	5.10	0.10	0.17	0.67	5.15	4.23	0.0001	0.11	0.81	40.00	6.56	82.14
Bt$_2$	80 -100	5.05	0.07	0.12	0.45	3.47	4.23	0.0001	0.12	0.80	0.20	6.49	82.14
Bt$_3$	100 -120	5.00	0.10	0.17	0.56	6.10	5.24	0.0001	0.11	0.81	0.10	6.49	85.07
Pedon 2 profile 2 coordinate N07^{0}45.600’ E09^0 45.064’ Elevation 495													
Ap	0 – 25	5.05	0.17	0.29	0.53	5.77	5.23	0.0001	0.12	0.80	0.15	6.50	85.04
AB	25 – 55	5.40	0.72	1.24	0.34	7.22	4.23	0.0001	1.90	0.80	0.25	5.54	61.04
BA	55 – 80	5.50	0.99	1.71	0.34	2.97	4.27	0.0001	0.09	0.81	0.20	6.34	82.59
B$_1$	80 – 100	5.60	0.48	0.83	0.36	8.34	5.25	0.0001	0.10	0.81	0.30	6.44	85.23
B$_2$	100 -120	5.70	0.75	1.23	0.39S	3.75	5.25	0.0001	0.10	0.72	0.40	6.56	86.49

OC = Organic Carbon, OM = organic Matter, TN = Total Nitrogen, CEC= Cation Exchange Capacity, AVP = Available Phosphorus K = Potassium, Na = Sodium, TEA = Total Exchangeable Acidity, Ca = Calcium, Mg = Magnesium.

Pedon 1

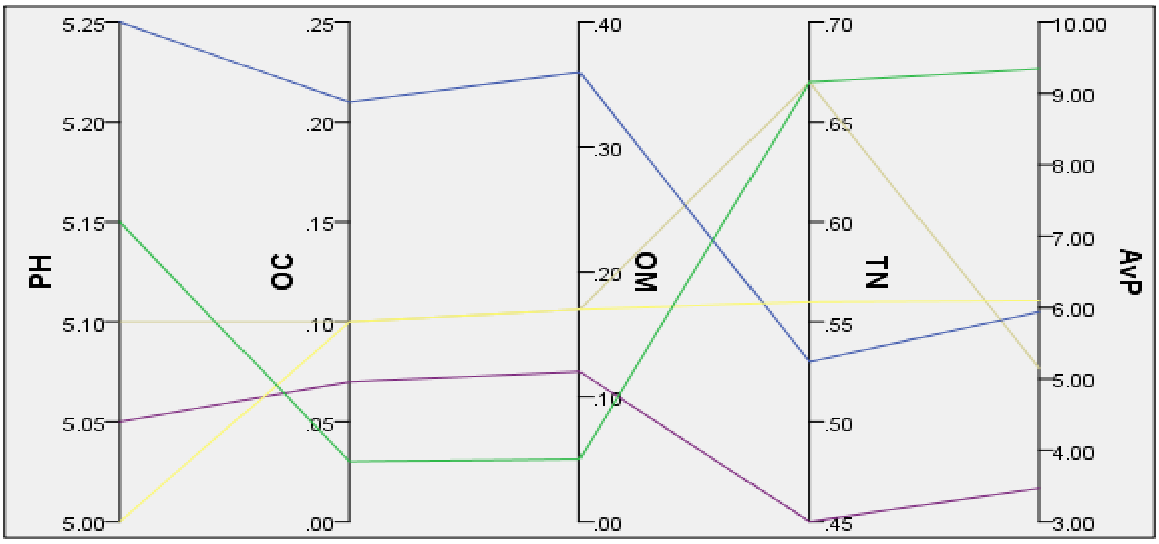

Figure 6. *Relationship between Soil pH, OC and Macro element*

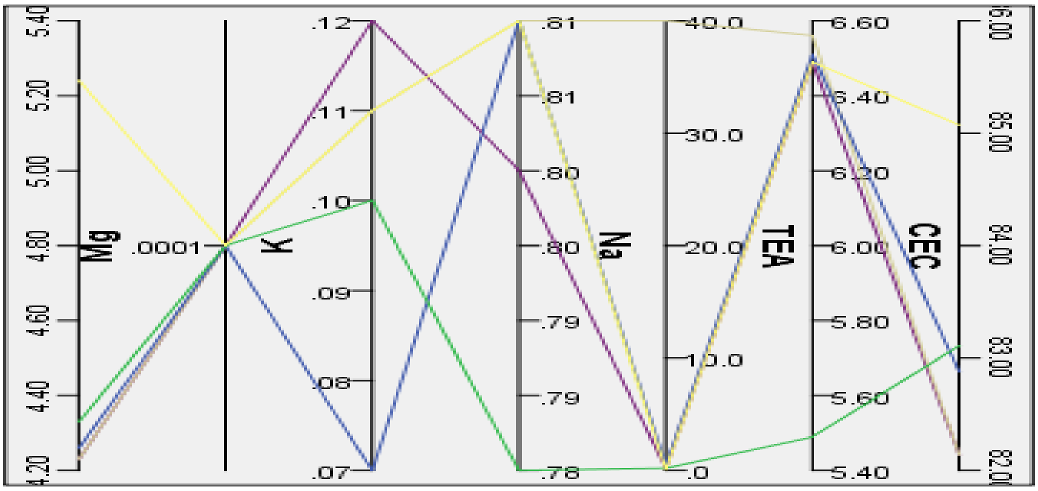

Figure 7. *Relationship between Basic Cations*

Pedon 2

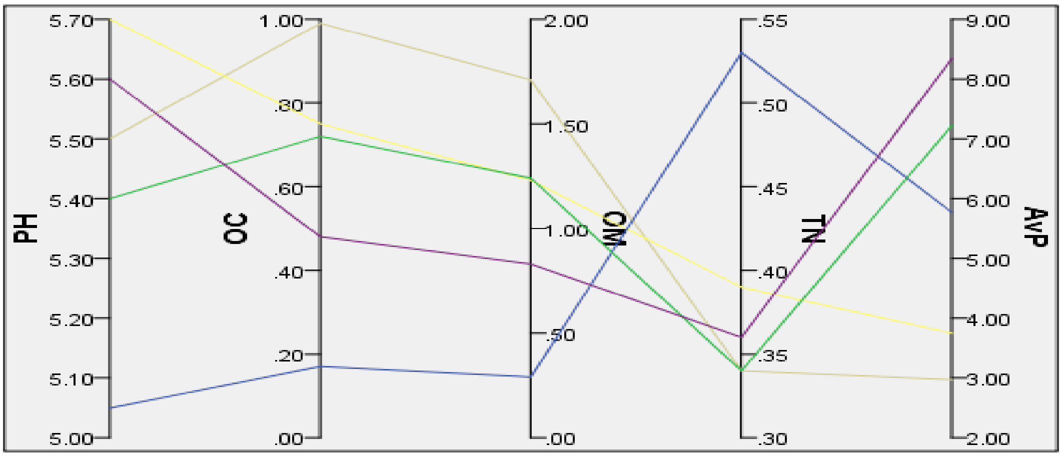

Figure 8. *Relationship between Soil pH, OC, OM, TN and AvP*

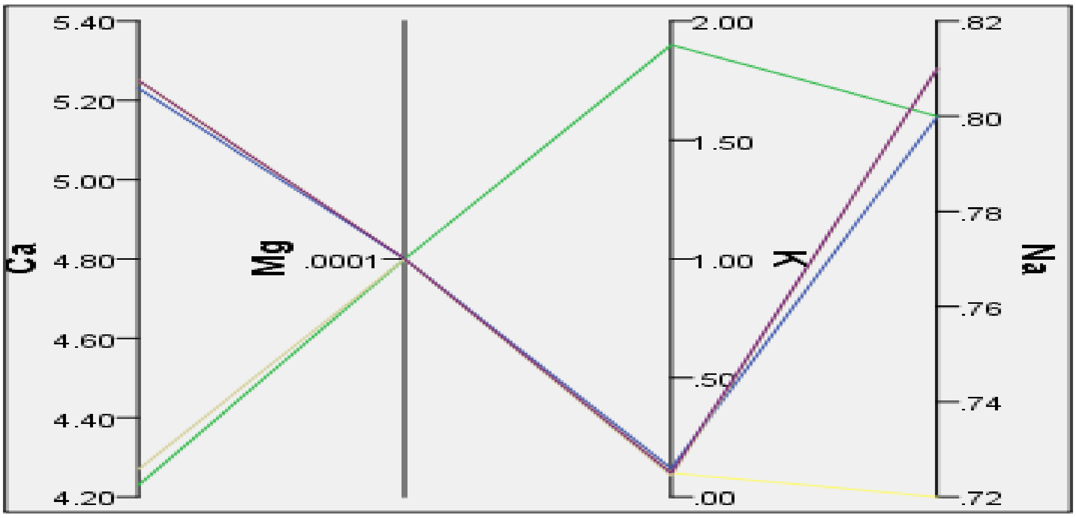

Figure 9. *Relationship between Basic cation*

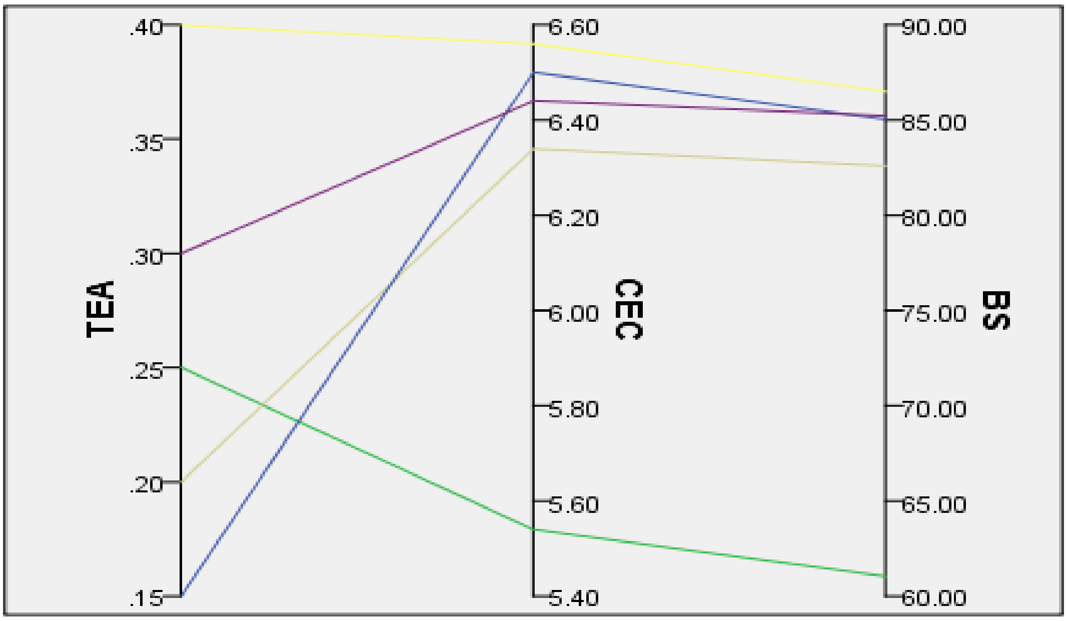

Figure 10. *Relationship between TEA, CEC and BS*

Table 4. *Soil Quality Rating for Wetland Rice*

Land quality	**Factor**	**Factor Rating**			
		S1	**S2**	**S3**	**N**
Temperature	Mean air Temp (^{0}C)	25–30	21–24	18–20	<18
			31–32	33-35	>35
Moisture	Mean Annual Rainfall (mm)	1200–2000	1000–1200	800–1000	<800
Growing period		500–800	400–500	300–400	<300
Air Humidity	Mean RH (%)	80	75–79	70–74	<70
Condition for					
1. Harvesting	Rainfall$\leq 80mm$/days	–	1–9	10	>10
2. Ripening	Air Temp (^{0}C)	–	18-19	–	<18
		20–29	30–32	33–40	<40
O_2 Availability	Drainage (class)	Poor	Somewhat poor,	Mod	Well
			Very poor	Well	Excessive
Rooting condition	Root depth (cm)	30–60	20–30	20–10	<10
	Stones & Gravel (%)	<5	5–15	15–35	>35
	Soil texture class	sand–clay	-	-	
Erosion	Slope (%)	<2	2–5	6–8	>8
Hazard	Observed erosion	None	None	None	None
Nutrient	Soil reaction ($_p$H)		5–5.9	4.3–4.9	<4.3
Available		6–7	7.1–7.9	8–8.3	>8.3
Salts	Soil salinity EC	<3	3–5	5.1–7.2	>7.2

Table 5. *Suitability Class Scores of the Pedons in the Study Area for Wetland Rice*

Land quality and characteristics	Soil Mapping Unit	
	1	**2**
Temperature	S_1	S_1
Moisture	S_2	S_3
Humidity	S_1	S_1
O_2 avail	S_2	S_3
Rooting depth	S_2	S_3
Gravels	S_1	S_1
Texture	S_1	S_3
Erosion	S_1	S_2
Nutrient	S_2	S_3
Salt	No data	
Suitability rating	S_2	S_2

Land Suitability Classification of the Study Area

The process of determining whether a piece of land is suitable for a certain purpose is known as land suitability evaluation (Ufot, 2012; Brady and Weil, 2014). The FAO (2016) states that land suitability grading entails matching crop needs with land characteristics. It is the suitability of particular soil characteristics for a particular type of land use. By contrasting the soil's characteristics with rice's needs, the appropriateness rating of a few chosen Wukari soils was determined. It was discovered that the chemical properties of the soils, including pH, organic carbon, CEC, exchangeable bases, exchange acidity, available P, and total N, were either favorable to rice production or could be changed by individual farmers, thus they cannot be regarded as long-term restrictions.

Water availability during the growth season is one of the rice crop's most critical needs (Idoga, 2005). Therefore, the most significant constraint on rainfed rice production is water. The key physical attributes that affect water retention include soil depth, drainage, slope, porosity, texture, and structure. Low-lying soil units I and II had a slope of 1% to 2%. They make it possible for water from the surroundings to accumulate, which results in aquic soil conditions. Water retention for plant usage is positively impacted by the soil's high clay content and sound structural development. Additionally, the grayed color (2.5Y) of these soils indicates that the ground/perched water table had a significant influence on them. Flooding and subterranean seepage are two further sources of water for the soils in the study area besides rainfall. The area's low nutrient status was indicated by the comparatively low levels of soil organic matter, total N, accessible P, CEC, and exchangeable bases (Table 3).

Because of their nutritional status and water availability, the soils in unit I were deemed to be fairly appropriate (S2) for growing rice. Approximately 66% of the research area is made up of the region's reasonably suitable soils. Unit II soils had complete saturation with the high-water level and were located at the lowest elevation in the region. The low-lying or depressional terrain and the soil's high clay composition prevent the soils from losing water as quickly as they did. The ustic moisture regime, low nutritional status, high porosity from the sandy character, and limited water-holding capacity were the main constraints for unit II soils. For a portion of the rice cropping season, water retention is positively impacted by the soil's good structural development and moderate clay concentration. Thus, it is classified as

S3 (Table 5), which is only marginally appropriate for rice production and may need irrigation during a one- to two-month drought and the application of organic or inorganic fertilizer. Approximately 12% of the research area is made up of the area's moderately suitable soils. This suggests that minimal human intervention is required by the one farmer who cultivates the entire wetland in order to achieve the highest possible rice harvest.

Conclusion

The suitability rating of selected Wukari soils for rice production indicated a moderately suitable (S2) in unit 1 and marginally suitable (S3) units II. Management practices such as organic matter incorporation, fertilizer application and time of planting have been recommended for improved rice productivity in the area studied.

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Soil Organic Matter Composition of Arenosols in Western Rhodopes Mountain, Bulgaria

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Abstract

The paper studies soil organic matter in sandy soils from Western Rhodopes region, which fall within the territory of Pazardzhik district of the South central planning region in Bulgaria. Brief information on the morphological characteristics of the soils established so far and their initial studies are presented. The composition of soil organic matter is determined by analysing its extractable (soluble) fractions and insoluble residue. The humus content of studied soils is discussed by comparison with soils of the same soil type and those with similar stage of development of soil-forming processes. The state of soil organic matter is evaluated according to various indicators related to the degree of humification, the state of humic acids and the type of humus in surface horizons.

Key words: Sandy soils, soil organic matter, humic acids, fulvic acid.

Introduction

In Bulgaria, the Arenosols are distributed in plains and hilly areas by the Black Sea coast and territories near the Danube River (Atanassova et al., 2013; Andreeva et al., 2016). Their predominant sand fraction was also found in soils from the terrace of Maritsa River, Plovdiv (Angelov & Vasileva, 2022), as well as in mountainous areas of the Western Rhodopes, Bulgaria (Hristov & Kirilov, 2023).

The Arenosols represent sandy azonal soils with different vegetation and relatively poorly developed soil profile (IUSS Working Group WRB, 2006). To a large extent, this is due to the predominant sandy fraction, determining the weak water-holding capacity of the soils, their high water permeability (Sapundzhiev, 2026; Andreeva et al., 2016), but also their susceptibility to appearance of certain water repellency in the surface horizon, in the cases of the presence of various hydrophobic compounds (Atanassova et al., 2013).

Sandy soils are low in nutrients (FAO and ITPS, 2015). The soil formation in them is in initial stage (Gyurov & Artinova, 2015) due to the unfavourable conditions and low accumulation of organic matter (Andreeva et al., 2016), which is essential for the management of these soils (Yost & Hartemink, 2019). The state of soil organic matter in sandy soils of the Bulgarian Black Sea coast is well studied (Kirilov, 2013), but in mountainous regions the research is still preliminary (Hristov & Kirilov, 2023).

The paper aim is to enrich the studies of Arenosols from mountainous regions of Bulgaria by characterizing the composition of soil organic matter.

Materials and Methods

Object of the study are soils from the region of the Western Rhodopes, which fall within the territory of the Pazardzhik District of the South central planning region in Bulgaria (Sapundzhiev & Mitreva, 2016; Regional administration Plovdiv, 2024). The soils are characterized by mechanical composition with predominant sand fraction and are established during a field trip by Hristov & Kirilov (2023) who study their morphological features in accordance with the Guidelines for soil description (Jahn et al., 2006) and conduct various laboratory analyses to determine diagnostic indicators in relation to soil classification. Hristov & Kirilov (2023) study 5 soil profiles and present data on their mechanical composition, carbon and nitrogen content, pH and physicochemical characteristics (sorption capacity, exchangeable cations, base saturation). As a result, the authors establish basic diagnostic characteristics of studied soils and classify them as Arenosols with the corresponding qualifiers according to the World Reference Base for Soil Resources – WRB (IUSS Working Group WRB, 2015).

For the present paper aim, the collected soil samples are analysed for determination of soil organic matter composition using the modified method of Tyurin (Kononova, 1963; Filcheva & Tsadilas, 2002). Surface horizons are studied because the total carbon content at depth in most of the soil profiles has low values (Hristov & Kirilov, 2023) that are below the limit of measurement accuracy, similar to some Technosols (Ivanov, 2007).

The discussions of the humus state of soils are carried out in accordance with the values from the Bulgarian classification for humus indicators in soils according to Artinova (Gyurov & Artinova, 2001).

The humus content is determined by calculating the values of total carbon with coefficient 1.724 (C x 1.724 = humus) (Kononova, 1963).

The degree of humification of organic matter is calculated based on the fraction of humic acids and total carbon content (C_h : C_{total} x 100 %), as indicated in the Artinova's classification (Gyurov & Artinova, 2001).

The type of humus is determined by the ratio between humic acids and fulvic acids, depending on the classification of Grishina and Orlov for humus indicators in soils (Orlov, 1985).

Results and Discussion

Arenosols are characterized by primitive soil profile (Atanassova et al., 2013) and poorly formed humus horizon (Gyurov & Artinova, 2015). These morphological features fully correspond to the studied soils, where the soil profile is of type A(AC) – AC – C with low thick humus horizon varying between 3 – 7 cm (Hristov & Kirilov, 2023). This defines soils as weakly organic, such as the Arenosols of the northeastern and northwestern regions of the Danube River Valley (Tsolova et al., 2018; Banov et al., 2018).

The data in table 1 present the results of the analysis carried out for establishment of the content and composition of soil organic matter in surface horizons of the soil profiles.

Table 1. *Content and composition of soil organic matter in surface horizons of studied Arenosols from the Western Rhodopes*

Profile №, horizon and depth (cm)	Total C, %	Organic carbon, %						Unextracted organic C, %	Extracted C in 0.1 N H_2SO_4	E_4/E_6	
		Extracted with 0.1M $Na_4P_2O_7$+0.1M NaOH			C_h/C_f	Humic acids fractions					
		Total	Humic acids	Fulvic acids		Free and bound with R_2O_3	Bound with Ca			Total humic acids	Free humic acids
1. A 0-3 cm	11.80	$\underline{3.26}$[a*] 27.62[b]	$\underline{1.92}$ 16.27	$\underline{1.34}$ 11.36	1.43	$\underline{1.79}$ 93.23[c]	$\underline{0.13}$ 6.77	$\underline{8.54}$ 72.37	$\underline{0.28}$ 2.37	6.58	6.67
2. A 0-3 cm	4.59	$\underline{1.11}$ 24.18	$\underline{0.64}$ 13.94	$\underline{0.47}$ 10.24	1.36	100.00	0.00	$\underline{3.48}$ 75.82	$\underline{0.05}$ 1.09	5.72	5.86
3. AC 0-2 cm	2.71	$\underline{0.86}$ 31.73	$\underline{0.44}$ 16.24	$\underline{0.42}$ 15.49	1.05	$\underline{0.42}$ 95.45	$\underline{0.02}$ 4.55	$\underline{1.85}$ 68.27	$\underline{0.05}$ 1.84	5.64	6.09
4. A 0-24 cm	0.80	$\underline{0.25}$ 31.25	$\underline{0.16}$ 20.00	$\underline{0.09}$ 11.25	1.78	0.00	100.00	$\underline{0.55}$ 68.75	$\underline{0.03}$ 3.75	5.12	-
5. Ah 0-7 cm	1.96	$\underline{0.44}$ 22.45	$\underline{0.22}$ 11.22	$\underline{0.22}$ 11.22	1.00	100.00	0.00	$\underline{1.52}$ 77.55	$\underline{0.05}$ 2.55	4.70	6.62

**a – % of soil sample; b – % of total carbon content; c – % of humic acids content*

Based on the amount of total carbon, the humus content varies from low to very high according to Artinova's Bulgarian classification of humus indicators in soils (Gyurov & Artinova, 2001) (figure 1). Its values are dependent on the developing vegetation and the presence of organic horizon in some soil profiles (Hristov & Kirilov, 2023), and no relationship with the thickness of humus-accumulative horizon is observed. Wide variations in the humus content are also characteristic of other soils such as Rankers and Rendzinas, which are part of general class of soils with poorly developed soil-forming process, in the Genetic classification of soils in Bulgaria (Teoharov, 2019a, b). However, this established range is not typical for all sandy soils, as the humus content of Arenosols from the Bulgarian Black Sea coast is low to very low (Kirilov et al., 2015). The probable reason for this differentiation is due to the conditions of soil formation related to soil-forming materials, altitude, climate and vegetation.

The humification of organic matter is medium to high depending on the content of humic acids according to Artinova (for Bulgarian soils) (Gyurov & Artinova, 2001) (figure 2). This soil characteristic of organic matter does not greatly distinguish the studied sandy soils from the Western Rhodopes from those along the Bulgarian Black Sea coast, which have slightly thicker surface horizons, and where even soil profiles with very high humification of organic matter in the surface (0-12 cm, 0-15 cm) sod horizons is established (Kirilov, 2013).

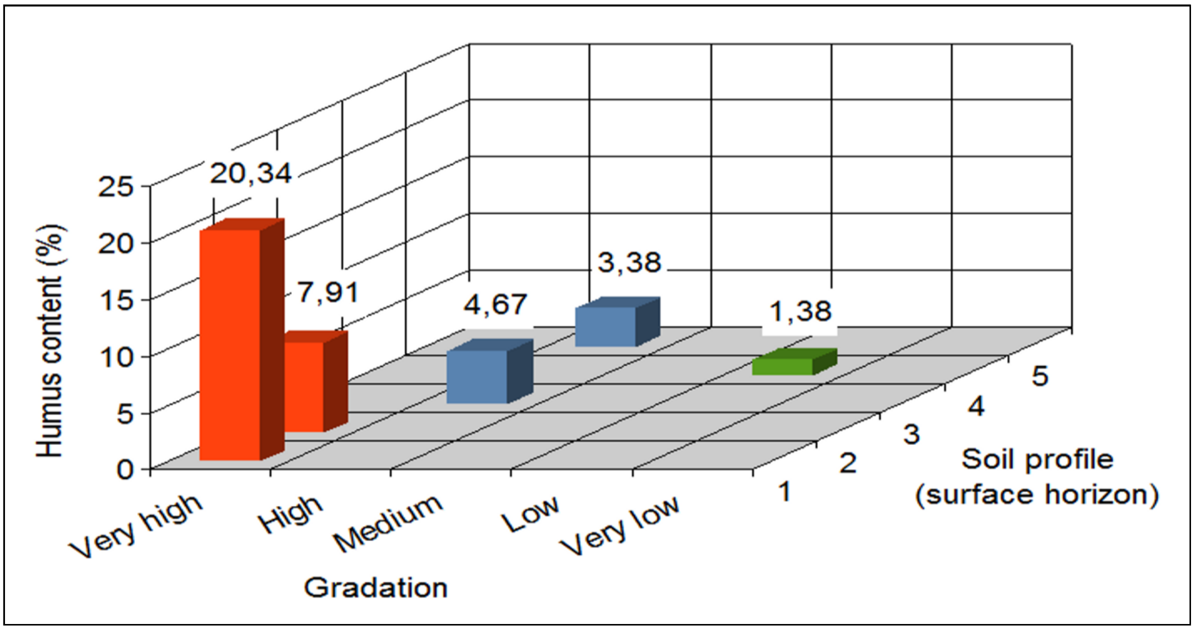

Figure 1. *Gradation of humus content in surface horizons of studied Arenosols from the Western Rhodopes*

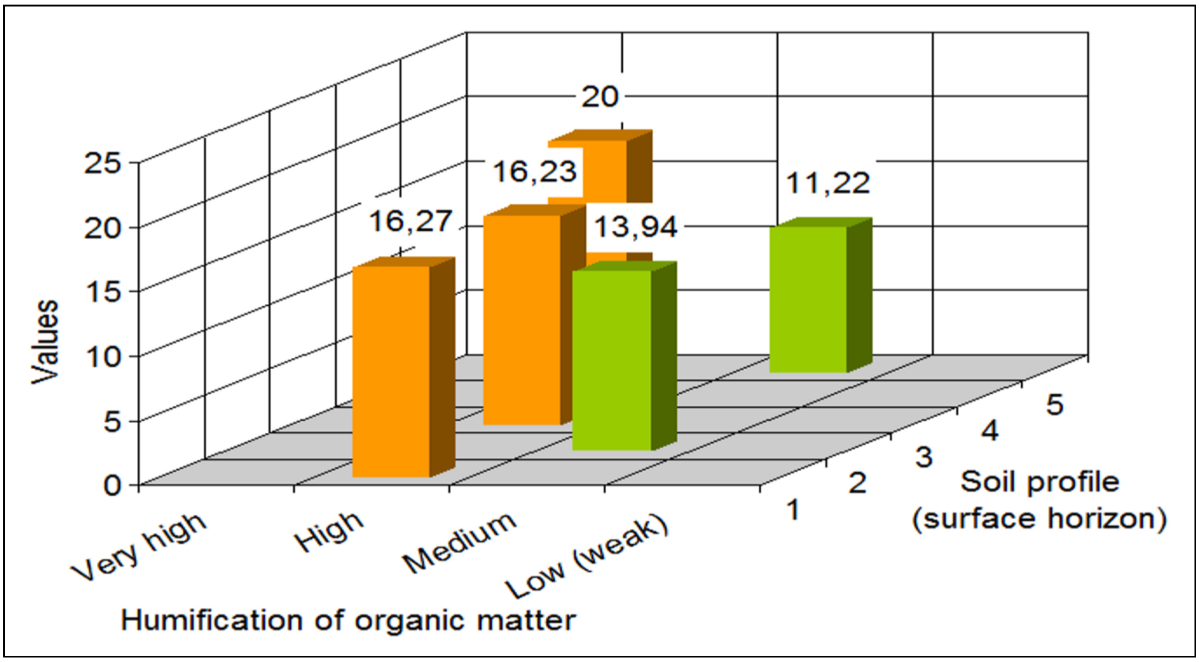

Figure 2. *Humification of organic matter in surface horizons of studied Arenosols from the Western Rhodopes*

It is noteworthy that the humic acids in studied soils are almost 100 % free and bound with R_2O_3 (table 1), which defines them as mobile (Shishkov & Filcheva, 2018). This may be related to the already found low values of calcium and magnesium in the composition of exchangeable cations (Hristov & Kirilov, 2023), since in soils with high base saturation, humic acids are 100 % bound with alkaline cations (Andreeva et al., 2011). An exception is profile 4, where humic acids are completely bound with calcium, but here the lowest total carbon values is found (table 1). This soil horizon is also characterized by the lowest content of total nitrogen, as well as highly acid reaction (Hristov & Kirilov, 2023) (table 2), depending on the classification of soils according to pH values (Koynov et al., 1980).

Table 2. *pH values and nitrogen content in surface horizons of studied Arenosols from the Western Rhodopes (Hristov & Kirilov, 2023)*

Profile №	Horizon, Depth (cm)	pH (H_2O)	Total N (%)
1	A 0 – 3	5.9	0.45
2	A 0 – 3	5.6	0.19
3	A 0 – 2	5.6	0.17
4	AC 0 – 24	4.9	0.06
5	Ah 0 – 7	5.6	0.08

Humic acids have slightly higher amount compared to fulvic acids (figure 3). Their ratio determines the fulvic-humic type of humus in the surface horizons of all profiles, depending on the classification of Grishina and Orlov for humus indicators in soils (Orlov, 1985). This shows that for profiles 1, 2 and 4, humification processes prevail over those of mineralization, while for profiles 3 and 5, these processes are equalized, similar to the surface horizons of soils from urban forest parks (Zhiyanski et al., 2012).

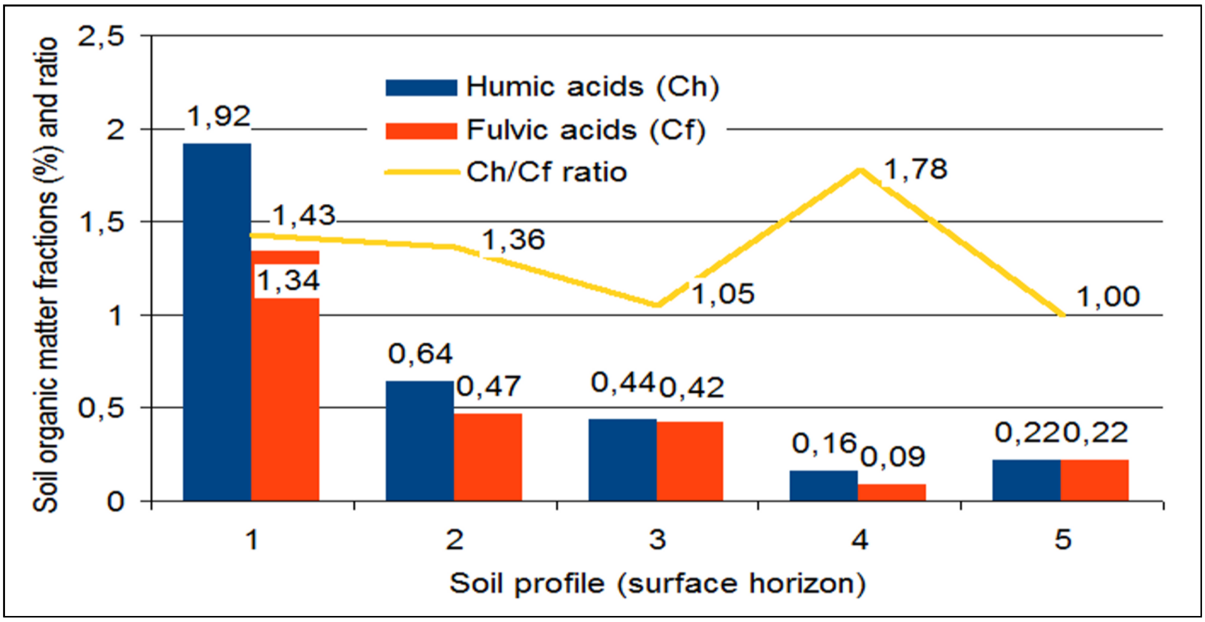

Figure 3. *Content of organic matter fractions (% of soil sample) and ratio in surface horizons of studied Arenosols from the Western Rhodopes*

The content of *aggressive fraction of fulvic acids* (Filcheva, 2007) is low in the studied soil samples. The insoluble fraction of organic carbon has greater ratio in the surface horizons of all studied soil profiles (Table 1), which may be related to the lack of suitable conditions for decomposition of plant residues (Kirilov et al., 2012).

The enrichment of humus with nitrogen in humus-accumulative horizons is very low to low depending on the humus indicators of soils according to Artinova (Gyurov & Artinova,

2001) (figure 4). In most of the subsurface horizons of studied soil profiles, this enrichment is also very low (Hristov & Kirilov, 2023). Exception is profile 4 where the C/N ratio determines medium enrichment of humus with nitrogen in the surface horizon (table 2). However, we will remind here the characteristics of this horizon related to the lowest carbon and nitrogen content and also the highly acid reaction of the environment (tables 1, 2), regardless of the developing grass vegetation and the distinctive morphologically established thickness (0-24 cm) (Hristov & Kirilov, 2023).

The optical density of humic acids (E4/E6) is average according to Artinova (2014) classification (table 1). These indicators of the humus condition of studied sandy soils have similar values in forest litter and humus-accumulative horizon of Brown forest soil (Cambisols) (Filcheva & Malinova, 2015). An exception is the surface horizon of profile 5, where the optical density compared to the total amount of humic acids is high (table 1). Similar results are found in the metamorphic horizon of the Cambisol, for which Filcheva & Malinova (2015) explain that in the first case (medium optical density) the humic acids are lower molecular, and in the second case (high optical density) their condensation is accelerated.

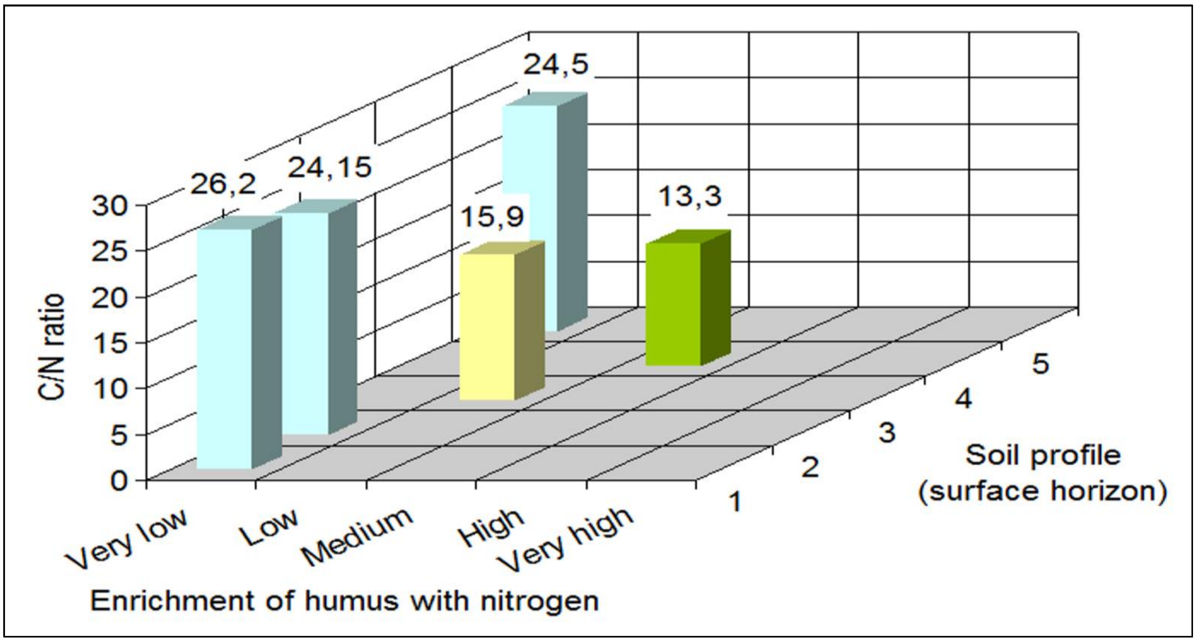

Figure 4. *Enrichment of humus with nitrogen (according to C/N ratio) in surface horizons of studied Arenosols from the Western Rhodopes*

Conclusions

The accumulation of humus in the surface horizons of studied sandy soils is not related to their morphologically determined thickness. The humification of organic matter is similar in soils of the same soil type, formed under different geological characteristics and climate conditions. The previously established physico-chemical characteristics of sandy soils influence the state of humic acids in the composition of soil organic matter.

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